

Author(s)	Clarke, Leo C.; Lawniczak, George E.
Title	Hemispheric solution of the Omega equation including terrain and surface frictional effects
Publisher	Monterey, California. Naval Postgraduate School
Issue Date	1962
URL	http://hdl.handle.net/10945/12283

This document was downloaded on April 24, 2015 at 04:56:21



<http://www.nps.edu/library>

Calhoun is a project of the Dudley Knox Library at NPS, furthering the precepts and goals of open government and government transparency. All information contained herein has been approved for release by the NPS Public Affairs Officer.

**Dudley Knox Library / Naval Postgraduate School
411 Dyer Road / 1 University Circle
Monterey, California USA 93943**



<http://www.nps.edu/>

NPS ARCHIVE
1962
CLARKE, L.

HEMISPHERIC SOLUTION OF THE OMEGA EQUATION
INCLUDING TERRAIN AND SURFACE
FRICTIONAL EFFECTS

LEO C. CLARKE
and
GEORGE E. LAWNICZAK, JR.

HEMISPHERIC SOLUTION OF THE OMEGA EQUATION
INCLUDING TERRAIN AND SURFACE FRICTIONAL EFFECTS

* * * * *

Leo C. Clarke
and
George E. Lawniczak, Jr.

HEMISPHERIC SOLUTION OF THE OMEGA EQUATION
INCLUDING TERRAIN AND SURFACE FRICTIONAL EFFECTS

by

Leo C. Clarke
//

Commander, United States Naval Reserve

and

George E. Lawniczak, Jr.

Lieutenant, United States Navy

Submitted in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE
IN
METEOROLOGY

United States Naval Postgraduate School
Monterey, California

1 9 6 2

HEMISPHERIC SOLUTION OF THE OMEGA EQUATION
INCLUDING TERRAIN AND SURFACE FRICTIONAL EFFECTS

by

Leo G. Clarke

and

George E. Lawniczak, Jr.

This work is accepted as fulfilling
the thesis requirements for the degree of

MASTER OF SCIENCE

IN

METEOROLOGY

from the

United States Naval Postgraduate School

ABSTRACT

A quasi-geostrophic omega equation for large-scale vertical velocities in the atmosphere is solved at the earth's surface, 850 mb, 700 mb, 500 mb, and 300 mb for a grid of 1977 points per level covering the major portion of the Northern Hemisphere. The effects of terrain and surface frictional stress on the vertical velocity at the lower boundary are investigated in some detail and applied at the earth's surface. The three-dimensional integration of the resulting equations excludes areas "inside" the terrain. The mathematical model is programmed for the Control Data Corporation 1604 digital computer to utilize the operational output of machine-processed data and analyses produced by the Fleet Numerical Weather Facility (FNWF), Monterey, California. The program allows a wide variety of modes of operation and yields a solution for ω in five minutes.

An unusual weather situation in January, 1962 is investigated and the results, though tentative, show that the correlation between computed vertical velocities and the observed weather is excellent.

The writers wish to express their appreciation to Professor George J. Haltiner of the U. S. Naval Postgraduate School for his guidance, contributions and assistance in this investigation.

Appreciation is expressed for the aid and cooperation of personnel at FNWF, especially to Mr. Milton H. Reese, who designed and programmed the initial phases of the machine computations. Gratitude is expressed to Mrs. Lillian F. Paine for her patience in typing this thesis.

TABLE OF CONTENTS

Section	Title	Page
1.	Introduction	1
2.	Method of Solution	2
3.	The Lower Boundary Condition	11
4.	Omega at the Lower Boundary	16
5.	Some Features of the Computer Program	23
6.	Discussion of Results	26
7.	Vertical Velocity Computations for a Particular Synoptic Situation	27
	Appendix A (Extracts from hemispheric prints of omega and relative vorticity fields)	43
	Appendix B (Cross sections of omega fields plus temperature, relative vorticity and stability for 0000Z 22 January 1962)	105
	Appendix C (Hemispheric charts of D values and temperatures plus stability for 0000Z 22 January 1962)	117
	Appendix D (TIROS observations and corre- sponding omega fields)	158
	Bibliography	171
	Transparent Overlay	173

LIST OF ILLUSTRATIONS

Figure		Page
1.	Definition of pressure finite differences	6
2.	Extrapolation scheme for D_T	12
3.	Internal boundary relationships	15
4.	Orientation of surface stress	18
5.	Extrapolation scheme for $(D_T)_p$	21
6.	Omega at lower boundary	27
7.	Omega at 850 mb with $C_J = 0$	28
8.	Omega at 700 mb with $C_J = 0$	29
9.	Omega at 500 mb with $C_J = 0$	30
10.	Omega at 300 mb with $C_J = 0$	31
11.	Omega at lower boundary	32
12.	Omega at 850 mb with terrain "in;" omega at 850 mb with terrain "out"	33
13.	Omega at 700 mb with terrain "in;" omega at 700 mb with terrain "out"	34
14.	Omega at 500 mb with terrain "in;" omega at 500 mb with terrain "out"	35
15.	Omega at 300 mb with terrain "in;" omega at 300 mb with terrain "out"	36

LIST OF SYMBOLS

ω	The vertical velocity of air in pressure coordinates
$()_{Lo}$	A subscript that specifies the value of a parameter at the lower boundary
ω_F	The frictionally induced ω at the top of the friction layer
θ	The potential temperature
$()_K$	The vertical component of the mesh ($K=1,2,\dots$); K increases with increasing pressure
R	The universal gas constant
f	The coriolis parameter, $2\Omega \sin \phi$, where Ω is angular speed of earth and ϕ is the latitude
f_o	The value of the coriolis parameter at the pole
f_m	The mean value of the coriolis parameter
g	The upward component of the apparent gravitational acceleration
ζ	The relative vorticity
η	The absolute vorticity
∇^2	The horizontal Laplacian operator on a constant-pressure surface
∇	The del operator on a constant-pressure surface
$J(A,B)$	The horizontal Jacobian operator
	$J(A,B) = \frac{\partial A}{\partial x} \frac{\partial B}{\partial y} - \frac{\partial B}{\partial x} \frac{\partial A}{\partial y}$
z	The height in centimeters
$()_T$	A subscript that specifies the value of a parameter at the terrain
c_p	The specific heat of dry air

S	The specific temperature anomaly
$S = \frac{\partial D}{\partial Z_p} = \frac{T - T_p}{T_p}$	
$()_{UL}$	Used as a subscript to specify difference of a parameter between two heights
Z_p	The pressure altitude in centimeters
d	The mesh dimension, 381 km
D	The altimeter correction, $D = Z - Z_p$
γ	The surface frictional stress
m	The map factor for a polar stereographic map projection true at 60N
$()_L, ()_U$	A subscript that specifies the value of a parameter at a lower (L)/upper (U) height
$(\hat{})$	A caret specifies that the quantity has been scaled into a fractional quantity
σ	The static stability, $\sigma = -\frac{1}{\theta} \frac{\partial \theta}{\partial p}$
p	The atmospheric pressure in millibars
$\nabla, \nabla^2, \Delta, \nabla$	Finite difference operators

1. Introduction

The value of vertical velocities in the atmosphere for understanding the basic weather phenomena associated with the large-scale features is gradually becoming more fully appreciated by synoptic forecasters [1]. The purpose of this investigation is to provide a means of computing these vertical velocity fields from routine weather charts and to examine the structure of these fields. Among the various methods for such determinations, the omega equation, derivable from the vorticity equation and the first law of thermodynamics, appears to afford the best means of computing large-scale vertical velocities from synoptic meteorological observations. Thus, the computer program developed for this omega equation is adaptable to operational use in a numerical forecasting center as well as for basic research.

The data used in this program are produced by the Fleet Numerical Weather Facility (FNWF), Monterey, California, essentially as follows [2]:

(a) Northern Hemisphere weather data are processed automatically by digital computer to yield reliable listings of surface and upper-air data.

(b) A Northern Hemisphere surface map is analyzed by digital computer and 1000-mb height and temperature charts are produced.

(c) The 850-mb, 700-mb, 500-mb and 300-mb height and temperature charts are then constructed with hydrostatic consistency by building upward from the 1000-mb level. Winds and off-time reports are also included.

(d) These surface and upper-air charts cover the entire Northern Hemisphere to the equator, and are produced at 0000 GCT and 1200 GCT daily. Further details are available at the Fleet Numerical Weather Facility.

2. Method of Solution

On the basis of the available data described above, it was decided to arrange the computational form of the omega equation so that only the data at a given constant-pressure level would be needed to calculate the parameters required in the iterative scheme for that level. This necessitated the use of unequally spaced pressure intervals in computing vertical derivatives, but gave the model some flexibility if additional levels became available or were changed.

The omega equation is derived from the vorticity equation (1), and the thermal equation (2) for adiabatic conditions by eliminating the local time derivatives jointly between the two equations.

$$\frac{g}{f} \nabla^2 \frac{\partial z}{\partial t} + \mathbf{V} \cdot \nabla \eta + \omega \frac{\partial f}{\partial p} = \eta \frac{\partial \omega}{\partial p} + \frac{\partial \omega}{\partial y} \frac{\partial u}{\partial p} - \frac{\partial \omega}{\partial x} \frac{\partial v}{\partial p}, \quad (1)$$

$$\frac{\partial T}{\partial t} + \mathbf{V} \cdot \nabla T - \omega \sigma = 0 \quad ; \quad \sigma = -\frac{T}{\theta} \frac{\partial \theta}{\partial p}, \quad (2)$$

where the various symbols are defined in Table of Symbols, page v.

The geostrophic approximation for vorticity has been made in the first term of equation (1). Operating on (1) with $\left(\frac{\partial}{\partial p}\right)$ and on (2) with $(-\nabla^2)$ and adding results in a form of the omega equation

$$\begin{aligned} \nabla^2(\sigma \omega) + \frac{pf\eta}{R} \frac{\partial^2 \omega}{\partial p^2} - \nabla^2(\mathbf{V} \cdot \nabla T) - \frac{pf}{R} \frac{\partial}{\partial p}(\mathbf{V} \cdot \nabla \eta) - \\ \frac{pf\omega}{R} \frac{\partial^2 f}{\partial p^2} + \frac{pf}{R} \frac{\partial}{\partial p} \left(\frac{\partial \omega}{\partial y} \frac{\partial u}{\partial p} - \frac{\partial \omega}{\partial x} \frac{\partial v}{\partial p} \right) = 0. \end{aligned} \quad (3)$$

The terms involving the vertical advection of vorticity and the twisting terms are usually of opposite sign and, moreover, small in comparison with the others remaining, and will be neglected as a first approximation. Of the terms which arise from the horizontal derivatives of σ ,

$$\nabla^2(\sigma\omega) = \sigma \nabla^2 \omega + \omega \nabla^2 \sigma + 2 \nabla \sigma \cdot \nabla \omega , \quad (4)$$

the last two on the right are also considered to be small in comparison with the first and will be neglected. The neglected terms may be incorporated along the lines used in Stuart [3], to afford a solution to the more complete equation (3). It is to be noted that σ will be allowed to vary in the horizontal as well as with pressure in this scheme. To evaluate partially the effect of the variable σ , the computer program has been designed to utilize alternately horizontal and vertical means of the static stability as well.

Neglecting the last two terms in (4) and substituting in (3) gives the reduced omega equation (5)

$$\sigma \nabla^2 \omega + \frac{p f_m^2}{R} \frac{\partial^2 \omega}{\partial p^2} - \nabla^2 (\mathbf{V} \cdot \nabla T) - \frac{p f}{R} \frac{\partial}{\partial p} (\mathbf{V} \cdot \nabla \eta) = 0 \quad (5)$$

where, in the second term, $f\eta$ has been replaced by f_m^2 to meet certain consistency requirements as described in [4] and [5]. Again, to evaluate the effect of this term, the computer program has both versions $f\eta$ and f_m^2 incorporated.

The third and fourth terms of (5) can be expanded using the geostrophic vorticity, $f = \frac{g}{f} \nabla^2 \bar{z}$,

the hydrostatic equation, and the equation of state:

$$\left[\nabla^2 (V \cdot \nabla T) - \frac{pf}{R} \frac{\partial}{\partial p} (V \cdot \nabla \eta) \right] =$$

$$\frac{g}{f} \left[-\nabla^2 J(Z, T) - \frac{f}{g} J(T, \eta) + J(Z, \nabla^2 T) \right].$$

Substituting this expression into (5) and rearranging gives the computational form of the reduced omega equation:

$$\nabla^2 \omega + \frac{pf_m^2}{\sigma R} \frac{\partial^2 \omega}{\partial p^2} = \frac{g}{f} \left[\nabla^2 J(Z, T) - J(Z, \nabla^2 T) - \frac{f}{g} J(T, \eta) \right] \quad (6)$$

The basic parameters involved above are Z and T . At a given level, the right side of (6) can be calculated from data at that level only. The last term on the right in (6) is generally considered to be of major importance and is used in the approximation made by Wiin-Nielsen [6].

The grid used is the Fleet Numerical Weather Facility Northern Hemisphere octagon of 1977 points centered on the pole and extending to about latitude 10N.

The omega equation (6) is to be solved at the four levels of 850 mb, 700 mb, 500 mb and 300 mb, with the lower boundary being the surface of the earth. The upper boundary is 100 mb where it is assumed that $\omega \equiv 0$, and the lateral boundaries are near 10N where it is also assumed that $\omega \equiv 0$.

To solve (6) numerically, the following finite-difference approximations, based on the adjoining five-point array, were used.

$$\oplus$$

$$2$$

$$\oplus$$

$$1$$

$$\oplus$$

$$0$$

$$\oplus$$

$$3$$

$$\oplus$$

$$4$$

For arbitrary quantities A and B;

$$\Delta_x = A_3 - A_1, \quad \Delta_y A = A_2 - A_4, \quad \Delta_R A = \left[(\Delta_x A)^2 + (\Delta_y A)^2 \right]^{\frac{1}{2}},$$

$$\Delta_x^2 A = A_3 + A_1 - 2A_0, \quad \Delta_y^2 A = A_2 + A_4 - 2A_0, \quad (7)$$

$$\nabla^2 A = \Delta_x^2 A + \Delta_y^2 A, \quad \nabla^2 A = \frac{m^2}{d^2} \nabla^2 A,$$

$$\overline{J}(A, B) = (\Delta_x A) \cdot (\Delta_y B) - (\Delta_y A) \cdot (\Delta_x B), \quad \overline{J}(A, B) = \frac{m^2}{4d^2} \overline{J}(A, B).$$

The portion of the term involving $p \frac{\partial^2 \omega}{\partial p^2}$ is approximated [4] by a finite-difference analog for unequal intervals

$$p \frac{\partial^2 \omega_K}{\partial p^2} \approx \frac{p}{\Delta_0 p} \cdot \frac{2 \Delta_K^2 \omega}{\Delta_K p} \quad (8)$$

where $\Delta_K^2 \omega = \omega_{K-1} - \frac{\Delta_K p}{\Delta_L p} \omega_K + \frac{\Delta_0 p}{\Delta_L p} \omega_{K+1}$

and $\Delta_0 p$, $\Delta_L p$ and $\Delta_K p$ are defined in figure 1.

SCHEMATIC VERTICAL SECTION

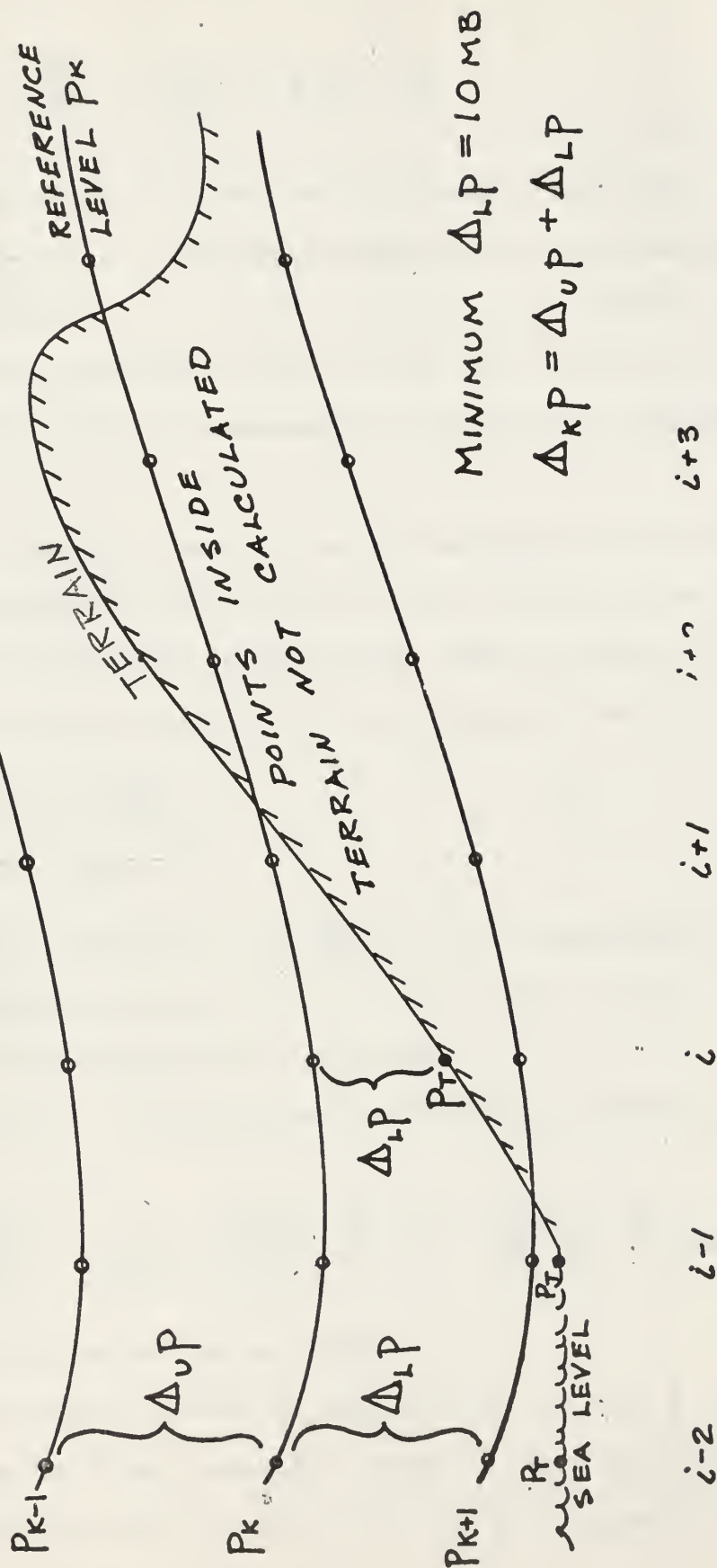


Figure 1. Definition of pressure finite differences.

The static stability

$$\sigma = -\frac{T}{\theta} \frac{\partial \theta}{\partial p} = \frac{RT}{p c_p} - \frac{\partial T}{\partial p} = \gamma_{p,D} - \gamma_p \quad (9)$$

is equal to the difference between the dry adiabatic lapse rate

$\gamma_{p,D} = RT/p c_p$ in pressure coordinates and the observed lapse rate $\gamma_p = \partial T / \partial p$. This form of the static stability parameter corresponds to that suggested by Gates [7] as "one of the more useful in modelling the large-scale disturbances in a troposphere of constant stability".

Since it is evident that the value of σ may approach zero or be negative, the magnitude of σ was controlled so that the second term of (6) remained positive and within certain bounds. This was done by requiring that the lapse rate not exceed 7/8 of the dry adiabatic lapse rate, namely,

$$\begin{aligned} \gamma_p &\leq 7/8 \cdot \gamma_{p,D} & \text{or} \\ \sigma &\geq \gamma_{p,D} \cdot 2^{-3}. \end{aligned} \quad (9A)$$

Comparison of the true σ with $\gamma_{p,D} \cdot 2^{-3}$ for a few synoptic cases has shown that this limiting criterion is very rarely, if ever, required when the input data are vertically consistent.

The second term of σ is approximated by the finite difference analog [8]

$$\left(\frac{\partial T}{\partial p} \right)_K \doteq \frac{\Delta_p T_K}{\Delta_u p} = \frac{1}{\Delta_K p} \left[\frac{\Delta_u p}{\Delta_L p} \cdot \Delta_L T_K + \frac{\Delta_L p}{\Delta_u p} \cdot \Delta_u T_K \right] \quad (10)$$

where Δ_L and Δ_u are defined in figure 1.

Sigma is expressed in units of degrees Kelvin per mb. In order to calculate sigma at 300 mb, temperature values at 100 mb are required. These data are not presently available from the Fleet Numerical Weather

Facility on a routine basis, and hence temperature values at 100 mb were approximated by either of the following schemes:

(a) The temperature at 100 mb was set equal to the 300-mb temperature. This approximates mid-latitude conditions and implies that a "tropopause" exists somewhere between the 300-mb and 100-mb levels, the specific pressure depending on the fitted parabola.

(b) A mean 100 mb temperature field is used based on a climatic summary. Since the synoptic case chosen for study was in January 1962, 5-year mean 100-mb temperatures for January (1949-1953) were used.

It is realized that neither of the above schemes is entirely satisfactory; however, the computer program is so arranged that synoptic analyses of 100-mb temperatures can be used when available on an operational basis.

In order to utilize established numerical sub-routines available at the FNWF as well as to minimize computational time, fixed-point fractional arithmetic was used exclusively in the computer program. Moreover, all parameters had to be scaled to have magnitudes less than one. The following standard FNWF scaling conventions were used:

$$\begin{aligned}
 \omega &= \hat{\omega} \cdot 2^n \text{ (mb} \cdot \text{sec}^{-1}) & n &= 8 \text{ at present} \\
 f &= \hat{f} \cdot 2^{-9} \text{ (sec}^{-1}) & \eta &= \hat{\eta} \cdot 2^{-9} \text{ (sec}^{-1}) \\
 D &= \hat{D} \cdot 2^{17} \text{ (cm)} & Z &= \hat{Z} \cdot 2^{20} \text{ (cm)} \\
 p &= \hat{p} \cdot 2^{11} \text{ (mb)} & \sigma &= \hat{\sigma} \cdot 2^3 \text{ (}^\circ\text{K} \cdot \text{mb}^{-1}) \\
 m &= \hat{m} \cdot 2^1 & T &= \hat{T} \cdot 2^9 \text{ (}^\circ\text{K or }^\circ\text{C)} .
 \end{aligned} \tag{11}$$

Substituting (7), (8), (9), (10), and (11) into (6) gives the

scaled difference equation that was programmed for the digital computer:

$$\nabla^2 \hat{\omega}_K - \hat{B}_K \cdot 2^{12} \cdot \hat{\omega}_K = \frac{2^{-n} \cdot b \cdot \hat{m}^2}{\hat{\sigma}_K \cdot \sin \phi} \left[\nabla^2 \hat{J}(\hat{D}_K, \hat{T}_K) - \hat{J}(\hat{D}_K, \nabla^2 \hat{T}_K) \right. \\ \left. - \frac{\hat{c} \cdot \sin \phi}{\hat{m}^2} \hat{J}(\hat{T}_K, \hat{\eta}_K) \right] - \hat{B}_K \cdot 2^{12} \left[\frac{\Delta_L \hat{p}}{\Delta_K \hat{p}} \cdot \hat{\omega}_{K-1} + \frac{\Delta_U \hat{p}}{\Delta_K \hat{p}} \cdot \hat{\omega}_{K+1} \right] \quad (12)$$

where

$$B_K = \hat{B}_K \cdot 2^{12} = 2^{-12} \left[2^{-24} \frac{f_m^2 d^2}{R} \cdot \frac{\hat{p}_K}{\Delta_U \hat{p}} \cdot \frac{\sin \phi}{\Delta_L \hat{p} \cdot \hat{m}^2 \cdot \hat{\sigma}_K} \right]$$

Letting $C_J \equiv$ First term on right in (12) ,

$C_{\hat{\omega}} \equiv$ Second term on right in (12) ,

equation (12) becomes

$$\nabla^2 \hat{\omega}_K - B_K \cdot \hat{\omega}_K = C_J - C_{\hat{\omega}} \equiv C_K, \quad K = 1, 2, \dots \quad (13)$$

These equations were solved by an accelerated Liebmann relaxation iterative scheme where the $(v+1)$ iterate at the point (i, j) is given by

$$\hat{\omega}_K^{v+1} = \hat{\omega}_K^v + \frac{\lambda \cdot R^v}{4 + B_K} \quad (14)$$

Here the residual R at each step is:

$$R^v = \nabla^2 \hat{\omega}_K^v - B_K \cdot \hat{\omega}_K^v - C_J + C_{\hat{\omega}}^v \quad (15)$$

The four pressure levels were successively scanned beginning at 850 mb and ending with the 300-mb level, this constituting one SCAN count

of 4(1977) = 7908 points in the 3-dimensional mesh.

Considering (13) as a system of Helmholtz equations, certain conditions regarding the coefficients must be fulfilled for convergence ('Arnason [9]) as follows.

$$(a) B_K > 0 \quad (16)$$

(b) The sum of the coefficients of ω_{K-1} and ω_{K+1} in $C\hat{\omega}$ in (13) must be less than or equal to one, including round-off errors

$$B_K \left[\frac{\Delta_L \hat{p}}{\Delta_K \hat{p}} + \frac{\Delta_U \hat{p}}{\Delta_K \hat{p}} \right] \leq B_K \quad (17)$$

The first requirement (16) is easily met since $\sigma_K > 0$ (see (9A)). The second requirement is sensitive because of the great range of the coefficient B_K , which can vary from a very small positive value (arbitrarily set to 2^{-46}) to values of the order of 2000. Both of these requirements are incorporated into the program.

The convergence criterion ϵ is defined as

$$\omega_K^{v+1} - \omega_K^v < \epsilon$$

for all points of the mesh. The ϵ is chosen so that no meteorologically significant changes will occur in the omegas if iteration were continued. The smallest value of interest was taken as $10^{-4} \text{ mb sec}^{-1}$ which is approximately equal to 0.1 cm sec^{-1} at 850 mb.

A number of different values of ϵ , ranging from 10^{-4} to $(1/6400) 10^{-4} \text{ mb sec}^{-1}$, were tried to determine an optimum ϵ . The final operational value adopted was $\epsilon_{25} = \frac{1}{25} \cdot 10^{-4} \text{ mb sec}^{-1}$

With this criterion, ϵ_{25} , convergence is reached, with the synoptic cases studied, in 14 to 15 SCANS as defined previously. For comparison purposes, convergence for $\epsilon_{100} = \frac{1}{100} \cdot 10^{-4} \text{ mb sec}^{-1}$ is obtained in about 26 SCANS.

The over-relaxation coefficient λ used was determined experimentally by finding that λ for which convergence was reached in the least number of SCANS for a given ϵ . This optimum λ is very sharply defined and was found to be 1.414. A λ differing from this value by roughly 10% increased the SCAN count by about 25%, and a change in value of only 0.1% changed the SCAN count by one.

3. The Lower Boundary Condition

The lower boundary condition was of special interest in devising this model [10]. In most previous studies, the given or calculated lower boundary values of omega were arbitrarily assigned to the lowest constant-pressure level in the model, usually 1000 mb, and then the family of equations was integrated with no regard to the presence or absence of mountainous features. The intersection of any pressure surface with the terrain constitutes an internal boundary within the mesh and is treated as such in this model. It is noted that, in order to find the intersection of the terrain and a given pressure level, the pressure at the terrain P_T must be known.

The input data at the various pressure levels (K) consist of D_K values and temperature T_K in degrees C. The definition of D is

$$D = Z - Z_p .$$

The D_T value at the height of the terrain Z_T is interpolated from the input data D_K by the principles of altimetry [11].

SCHEMATIC VERTICAL SECTION

$$S_{UL} = \frac{D_U - D_L}{Z_{PU} - Z_{PL}}$$

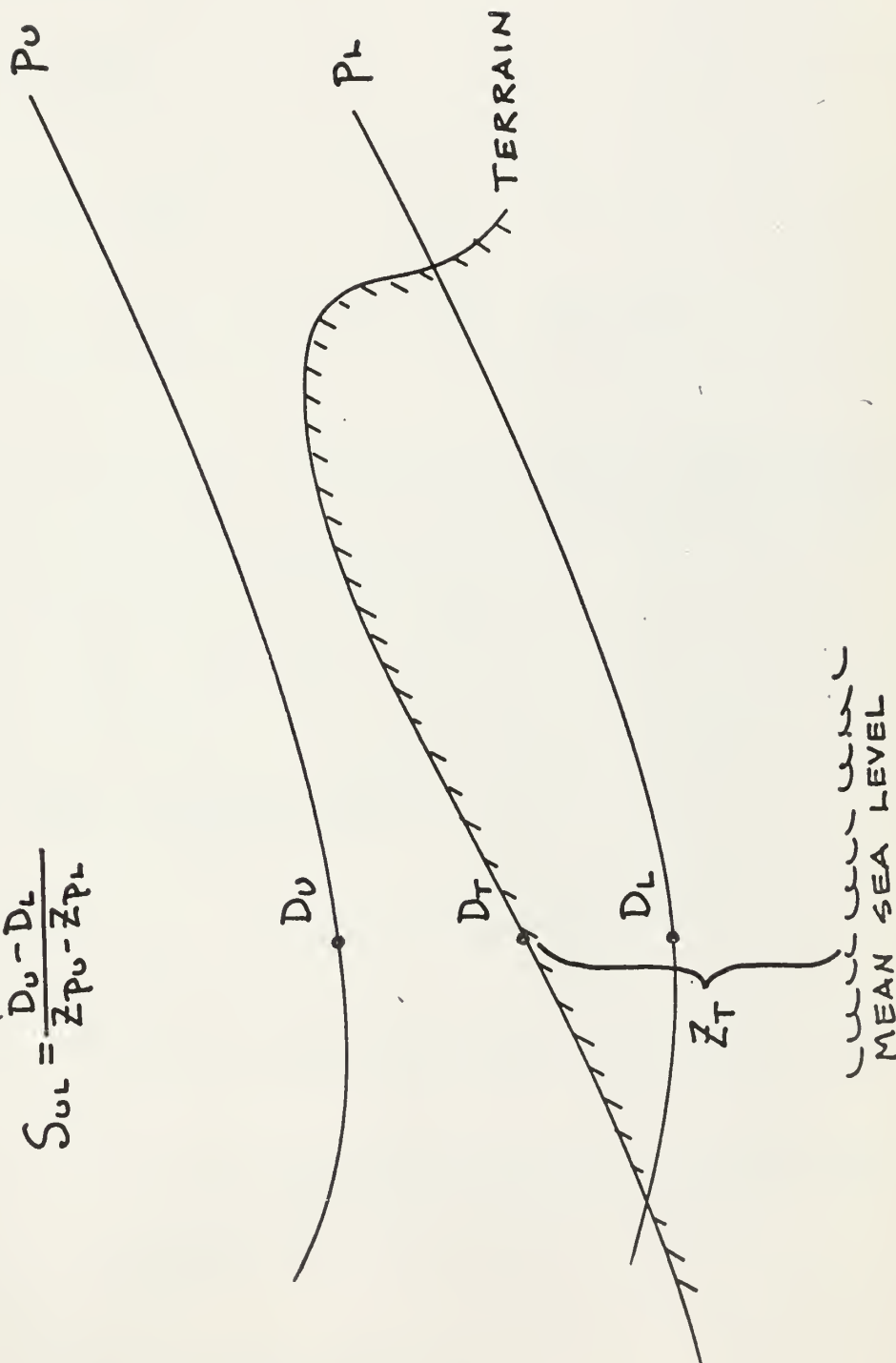


Figure 2. Extrapolation scheme for D_T

Let

$$\Delta_{UL} D \equiv D_U - D_L$$

$$\Delta_{UL} Z_P \equiv Z_{P_U} - Z_{P_L} \quad (18)$$

$$\Delta_{UT} Z_P \equiv Z_{P_U} - Z_{P_T}$$

$$\Delta_{UT} D \equiv D_U - D_T \quad \text{or} \quad D_T = D_U - \Delta_{UT} D$$

To find $\Delta_{UT} D$, the specific temperature anomaly $S_{UL} = \Delta_{UL} D / \Delta_{UL} Z_P$ is calculated. This S_{UL} value is the mean for the column P_U to P_L .

Applying it to the portion from P_U to P_T

$$\Delta_{UT} D = S_{UL} \cdot \Delta_{UT} Z_P$$

Substituting in (18) gives

$$D_T = \frac{D_U - S_{UL}(Z_{P_U} - Z_T)}{1 + S_{UL}} \quad (19)$$

Having interpolated D_T , the pressure altitude is then

$$Z_{P_T} = Z_T - D_T$$

and P_T can be obtained from Z_{P_T} since there is a one-to-one correspondence of values.

For the last step, an interpolating polynomial is developed that gives the terrain pressure with accuracy within one millibar.

The polynomial is

$$P_T = y(a + by^2) + u(c + du^2) \quad (20)$$

where

$$a = 724.64$$

$$c = 597.37$$

$$b = 3.5562$$

$$d = 3.1272$$

$$y = 1 - u$$

$$u = \frac{Z_{PT} - 2.7 \cdot 10^5}{1.5 \cdot 10^5} .$$

The scaled polynomial is then

$$\hat{p}_T = 2^5 [\hat{y}(\hat{a} + \hat{b} \hat{y}^2) + \hat{u}(\hat{c} + \hat{d} \hat{u}^2)] ,$$

where

$$\hat{a} = 4.4229 \cdot 10^{-2}$$

$$\hat{b} = 3.4729 \cdot 10^{-3}$$

$$\hat{c} = 3.6461 \cdot 10^{-2}$$

$$\hat{d} = 3.0539 \cdot 10^{-3}$$

$$u = \hat{u} \cdot 2^2$$

$$y = \hat{y} \cdot 2^2$$

$$\hat{u} = \frac{\hat{Z}_{PT} - 0.25749}{0.57220}$$

$$y = 2^{-2} - \hat{u} .$$

The pressure at the terrain is calculated on a synoptic basis and is used in devising a marker field which controls the iterative scheme so that all points of the mesh which "lie" within the terrain are not relaxed and constitute an internal boundary. At the surface of the terrain a value of ω_{LO} is computed as described later. This ω_{LO} value is assigned to the same grid point at all greater pressure levels, i.e., those within the terrain. This substitution is illustrated schematically in figure 3. Note that under this scheme, the Laplacian of ω at (i') involves the uses of $(\omega_{LO})_{i'}$, which generally more closely approximates the value of ω_A than if zero were used.

SCHEMATIC VERTICAL SECTION

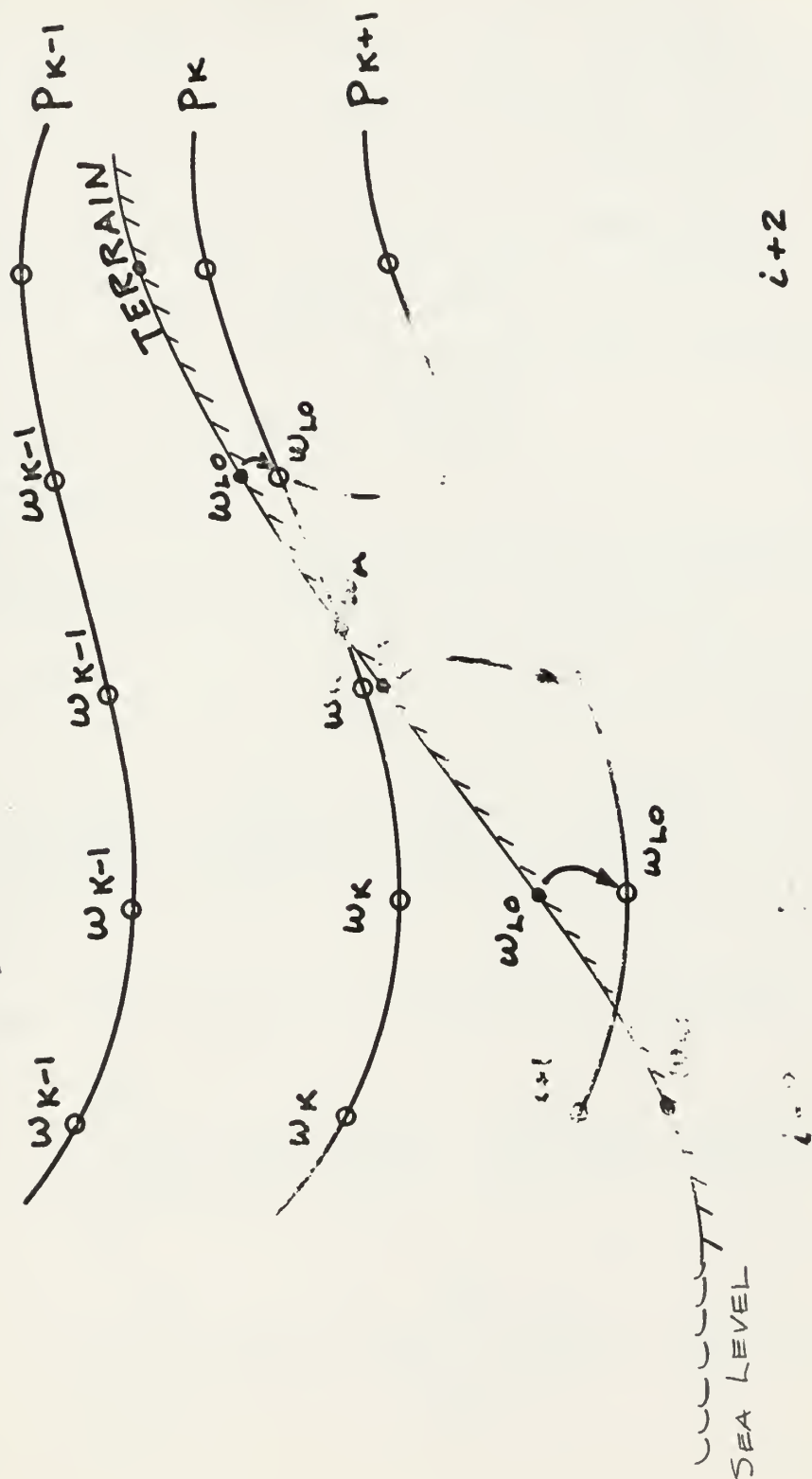


Figure 3. Internal boundary relationships.

4. Omega at the Lower Boundary

The pressure at the terrain P_T is also used to calculate the omega at the lower boundary, ω_{LO} . The combined effect of the frictionally-induced vertical velocity and the vertical velocity due to the slope of terrain will be calculated for the volume of air bounded by the surface of the earth at pressure P_T and at the top by a pressure P_{LO} where the surface frictional stress is assumed to vanish. The net inflow or convergence into this volume results in a vertical velocity ω_{LO} through the upper boundary. If the equation of continuity

$$-\frac{\partial \omega}{\partial p} = \nabla \cdot \mathbf{V} \quad (21)$$

is integrated through the friction layer, $P_T - P_{LO}$, utilizing the wind \mathbf{V} ,

$$\mathbf{V} = -\frac{1}{f} \left[\frac{\partial \phi}{\partial y} + g \frac{\partial \hat{\tau}_y}{\partial p} \right] \hat{i} + \frac{1}{f} \left[\frac{\partial \phi}{\partial x} + g \frac{\partial \hat{\tau}_x}{\partial p} \right] \hat{j}, \quad (22)$$

where $\hat{\tau}_x$ and $\hat{\tau}_y$ are components of the stress, there results

$$\begin{aligned} \omega_{LO} - \omega_T &= \int_{P_T}^{P_{LO}} \left\{ \frac{\partial}{\partial x} \left[\frac{1}{f} \frac{\partial \phi}{\partial y} + g \frac{\partial \hat{\tau}_y}{\partial p} \right] - \frac{\partial}{\partial y} \left[\frac{1}{f} \frac{\partial \phi}{\partial x} + g \frac{\partial \hat{\tau}_x}{\partial p} \right] \right\} dp \\ &= \frac{1}{f} \int_{P_T}^{P_{LO}} (\mathbf{V}_g \cdot \nabla f) dp + \frac{g}{f} \int_{P_T}^{P_{LO}} \left[\frac{\partial \hat{\tau}_y}{\partial x} - \frac{\partial \hat{\tau}_x}{\partial y} \right] dp \end{aligned}$$

$$\begin{aligned}
&= \frac{1}{f} \int_{p_T}^{p_{Lo}} \beta v dp + \frac{g}{f} \left[\frac{\partial \tau_y}{\partial x} - \frac{\partial \tau_x}{\partial y} \right]_{p_{Lo}} - \frac{g}{f} \left[\frac{\partial \tau_y}{\partial x} - \frac{\partial \tau_x}{\partial y} \right]_{p_T} \\
&= - \frac{\beta}{f} \bar{u}_g (p_T - p_{Lo}) + \frac{g}{f} \left[\frac{\partial \tau_{ox}}{\partial y} - \frac{\partial \tau_{oy}}{\partial x} \right], \quad (23)
\end{aligned}$$

where τ_o is surface stress at p_T

and $\tau_x = \tau_y = 0$ at p_{Lo} .

The first term on right in (23) is usually small in comparison with the other terms and is neglected. Setting $\omega_{Lo} - \omega_T \equiv \omega_F$, the frictionally induced vertical velocity (23) may be written as

$$\omega_F = \frac{g}{f} \left[\frac{\partial \tau_{ox}}{\partial y} - \frac{\partial \tau_{oy}}{\partial x} \right]. \quad (24)$$

If it is assumed (Lettau [12]) that the surface stress is opposite the direction of the wind, V_T , making an angle α with the isobars, (see figure 4), then

$$\tau_{ox} = \tau_o \cos \alpha, \quad \tau_{oy} = \tau_o \sin \alpha.$$

The surface stress is further assumed to be proportional to the square of the wind at the top of friction layer in the manner of Lettau [11] and Cressman [10], i.e., $\tau_o = C_D \rho_{Lo} V_{Lo}^2$

$$\text{and } \tau_{ox} = C_D \rho_{Lo} u_{Lo} V_{Lo}, \quad \tau_{oy} = C_D \rho_{Lo} v_{Lo} V_{Lo}. \quad (25)$$

ON CONSTANT PRESSURE SURFACE

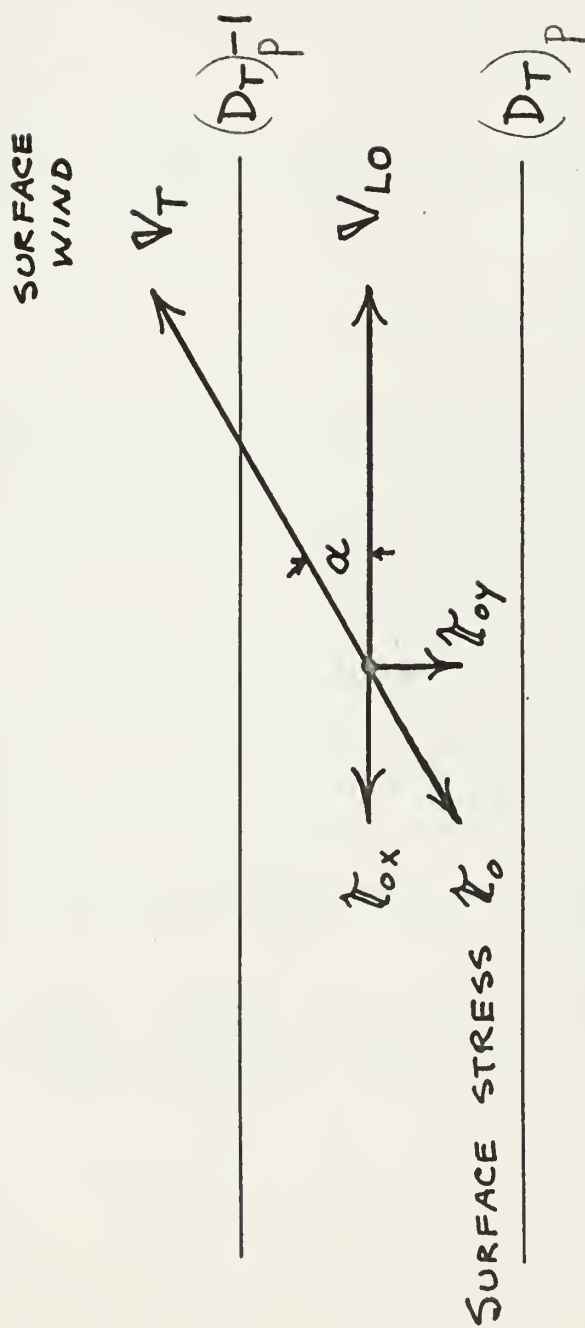


Figure 4. Orientation of surface stress.

Then from (24)

$$\omega_F = \frac{g\bar{\rho}_{L0}}{f} \left[\frac{\partial(C_D u_{L0} V_{L0})}{\partial y} - \frac{\partial(C_D v_{L0} V_{L0})}{\partial x} \right],$$

where the local variation of density has been neglected. Expanding this equation

$$\omega_F = \frac{g\bar{\rho}_{L0}}{f} \left[C_D V_{L0} \left(\frac{\partial u_{L0}}{\partial y} - \frac{\partial v_{L0}}{\partial x} \right) + u_{L0} \frac{\partial(C_D V_{L0})}{\partial y} - v_{L0} \frac{\partial(C_D V_{L0})}{\partial x} \right]. \quad (26)$$

The last two terms on the right in (26) were assumed small in comparison with the first and were neglected. The surface friction omega can then be written as

$$\omega_F = - \frac{g P_T}{f R T_T} C_D V_{L0} f_{L0}, \quad (27)$$

where the density has been replaced through the equation of state.

Next, the vertical velocities due to varying terrain height will be considered. The value of omega due to the terrain slope ω_T may be written in the form

$$\omega_T = \left(\frac{d\omega}{dp} \right)_T = \left(\frac{\partial p}{\partial t} \right)_T + V_{L0} \cdot \nabla p_T. \quad (28)$$

For a large 3-hourly tendency

$$\left(\frac{\partial p}{\partial t} \right)_T \doteq 5 \text{ mb per 3 hr}$$

and will be neglected. Then

$$\omega_T \doteq V_{L0} \cdot \nabla p_T, \quad (29)$$

and omega at the lower boundary is

$$\omega_{L0} = \omega_T + \omega_F = V_{L0} \cdot \nabla p_T - \frac{g p_T}{f R T_T} C_D V_{L0} \beta_{L0} \quad (30)$$

The geostrophic wind at the lower boundary V_{L0} is required in (30) in both terms. The geostrophic vorticity β_{L0} is also required and is based on V_{L0}

$$V_{L0} = K \times \frac{g}{f} (\nabla_p D)_T \quad (31)$$

Here it is noted that $\nabla_p D$ must be determined at terrain pressure. Thus it is necessary to "reduce" or extrapolate the D_T values at points surrounding the central point. These extrapolated values will be called $(D_T)_p$. The extrapolation will be done on altimetry principles using the previously calculated S_{UL} values for the layer in which the terrain lies. For example, in figure 5, at point $(i+1)$, the extrapolated value is

$$(D_T)_{p,i+1} = (D_T)_{i+1} + (S_{UL})_{i+1} [Z_{p,i} - Z_{p_T,i+1}] \quad (32)$$

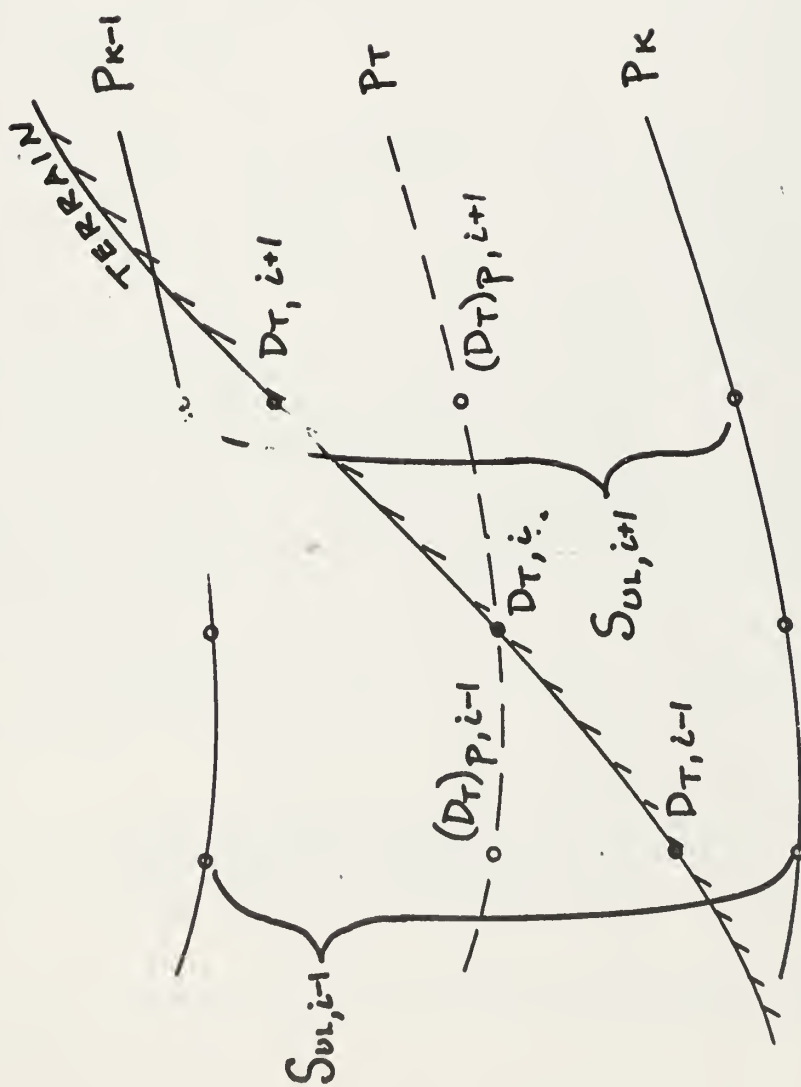
It follows that the gradient of D in the x-direction may be written

$$\begin{aligned} (D_T)_{p,i+1} - (D_T)_{p,i-1} &= [D_{T,i+1} - D_{T,i-1}] - Z_{p,i} [(S_{UL})_{i+1} - (S_{UL})_{i-1}] \\ &\quad + (S_{UL})_{i-1} \cdot Z_{p_T,i-1} - (S_{UL})_{i+1} \cdot Z_{p_T,i+1} \end{aligned} \quad (33)$$

Similar considerations hold for the y-component. Both equations (32) and (33) are used in making calculations of V_{L0} and β_{L0} for use in equation (30).

The T_T in equation (30) is also calculated by altimetry principles [9]. By definition, the specific temperature anomaly is

SCHEMATIC VERTICAL SECTION



$i-1$ i $i+1$

Figure 5. Extrapolation scheme for $(D_T)_p$

$$S = \frac{T - T_p}{T_p} , \quad (34)$$

where T_p , the pressure temperature, is the standard-atmosphere temperature at a given pressure altitude and T is the temperature at a given point. Solving (34) for T and applying to this model gives

$$T_T = T_{p_T} (1 + S_{uL}) . \quad (35)$$

The pressure temperature T_{p_T} is given by

$$T_{p_T} = T_{p_0} - a \cdot Z_{p_T} \quad (36)$$

where $T_{p_0} = 15^\circ\text{C}$ is the temperature at $Z_p = 0$

and $a = 6.5 \cdot 10^{-5}^\circ\text{C per cm}$.

Combining (35) and (36) yields

$$T_T = (T_{p_0} - a \cdot Z_{p_T}) (1 + S_{uL}) . \quad (37)$$

Substituting (31), (32), (36) and the geostrophic vorticity into (30) gives the computational forms for ω_T and ω_F

$$\omega_T = \frac{g}{f} \mathcal{J}[(D_T)_p, p_T] , \quad (38)$$

$$\omega_F = - \frac{g^3 \cdot p_T \cdot C_D \cdot |\mathbf{k} \times (\nabla_p D)_T| \cdot \nabla^2 (D_T)_p}{f^3 \cdot R (T_{p_0} - a \cdot Z_{p_T}) (1 + S_{uL})} . \quad (39)$$

Using the finite difference analogs (7) and the standard scaling conventions (11) gives

$$\hat{\omega}_T = \frac{2^{-n} c \hat{m}^2}{\sin \phi} \mathcal{J}[(\hat{D}_T)_p, \hat{p}_T] , \quad (40)$$

$$\hat{\omega}_F = - \frac{2^{38-n} \cdot C_D \cdot g^3 \cdot \hat{m}^3 \cdot \hat{P}_T \cdot \Delta_R(\hat{D}_T)_P \cdot \nabla^2(\hat{D}_T)_P}{f^3 \cdot \sin^3 \phi \cdot d^3 \cdot R \cdot (T_{P0} - \hat{\alpha} \hat{Z}_{PT}) (1 + S_{OL})} \quad (41)$$

The $\hat{\omega}_{LO}$ is then $\hat{\omega}_{LO} = \hat{\omega}_T + \hat{\omega}_F$.

The computational time to obtain $\hat{\omega}_{LO}$ is about 40 seconds.

The coefficient of drag C_D in (30) is the same as that defined by Cressman [13], and values of C_D were obtained from the Joint Numerical Prediction Unit, United States Weather Bureau, Suitland, Maryland.

The height of the terrain \hat{Z}_T is an area-smoothed value, and for the synoptic cases presented the heights used were obtained from the FNWF. The terrain heights have certain deficiencies due to rather heavy smoothing. They are being replaced with values averaged over a 1-degree latitude/longitude area, as determined by Berkofsky and Bertoni [14].

5. Some Features of the Computer Program

The Control Data Corporation 1604 digital computer was used in this investigation. It has a core memory of 32,768 words of 48 bits each, with a typical add time of 7.2 microseconds.

The initial "guess" field for omega at the various pressure levels is obtained from the ω_{LO} value previously computed. It was expected that the influence of a particular ω_{LO} at the lower boundary would decrease nearly exponentially with height above the terrain, hence the initial guess field was computed by $\omega_K^{(0)} = \omega_{LO} \cdot 2^{-t}$,

where $t = 1$ for the first pressure level above the terrain, $t = 2$ for the second, etc. This procedure accelerates the convergence of the relaxation scheme appreciably, as compared to an initial guess field of zero.

Provision is made in the computer program to determine the influence

of the lower boundary on the omega fields in various ways.

(a) The terrain-induced vertical velocity ω_T and the frictionally-induced velocity ω_F may be calculated separately or jointly.

(b) ω_{LO} may be set equal to zero. Here the terrain is still present and the lower boundary follows the variable height of the surface of the earth.

(c) The computation scheme can be altered to test the effect of inserting the ω_{LO} values at an artificial lower boundary, calculated on the assumption that the height of the terrain is zero. The pressure at this lower boundary is not constant and corresponds to the sea-level pressure map. This simulates closely the approximations normally used [3], [10], [13], wherein the lower boundary values are arbitrarily assigned to the lowest constant-pressure level of the model. Thus, they are not only applied at an incorrect altitude, but ignore the presence of internal boundaries due to the intersection of pressure surfaces and terrain.

(d) The forcing function C_T of equation (13), which involves the D- and T-fields responsible for the large-scale vertical velocities, can be set equal to zero and a solution obtained with only the lower boundary values ω_{LO} present. This essentially shows the decay of the influence of the ω_{LO} with height, subject here only to the static stability variations in the atmosphere (see equation (6)).

Examples of the various possibilities (a) to (d) will be given in the next section.

Many modes of operation of the computer program are possible and allow a wide variety of side products to be obtained if desired. The more important of these are listed below.

D_k at 5 levels

T_k at 6 levels

σ_k at 4 levels

S_{UL}

P_T

T_T

ω_T

ω_F

ω_{LD}

ϕ_k at 4 levels

ω_k at 4 levels

All of these can be obtained in computer-analyzed form on machine-drawn and labelled charts. All the charts of this investigation were produced in this manner except cross sections.

It is to be noted that on the charts of ω_k wherever the terrain projects through a pressure level, the value +111 is printed at that grid point, and delineates the internal boundary.

The computer program has "smoothers" incorporated to control irregularities in higher-order finite differences of the input data. These smoothers are of the form

$$\tilde{A}_{ij} = A_{ij} + K \nabla^2 A_{ij} ,$$

where \tilde{A} is the smoothed data,
A is the unsmooth data,
and K is the smoothing coefficient and is equal to 1/8.

This smoother is applied once to the $\nabla^2 \hat{D}_K$, $\nabla^2 \hat{T}_K$, and $\nabla^2 \hat{J}(\hat{D}_K, \hat{T}_K)$ fields.

6. Discussion of Results

The static stability is a bulk value, since it is derived by fitting a parabola to temperatures from three pressure levels of hydrostatically-checked analyses. The computed σ_K vary as expected with regard to the relative stability characteristics of various air masses at lower levels and with respect to the proximity of the stratosphere at upper levels. The observed rapid variation of the static stability may not justify the neglect of the derivatives of σ_K in certain areas. These effects are to be included in future computations. Some typical charts are displayed in Appendix C, pages 136, 139, 142, and 145.

The influence of the lower boundary on the vertical velocity field was investigated, and some typical charts of the results are displayed in figures 6 to 10. Note that the decay of velocity with distance from the surface of the earth is very rapid, and even large values of ω_{L0} (at levels below 850 mb) do not exert a significant influence beyond the 500-mb level.

In many models, the vertical velocity at the lower boundary is artificially assigned to the lowest pressure level of the model. The present model was constrained to operate in this mode for a few tests, one of which is presented in figures 11 to 15. Inspection shows that, as expected, there is little disagreement in areas where the terrain is near zero height, but large discrepancies arise at those points in the vicinity of prominent terrain features. Areas where this disagreement is the largest are obviously the Cordilleras of North America and the Himalayan Plateau of Asia. The transparent overlay at the end of this report may be used on figures 6 through 10.

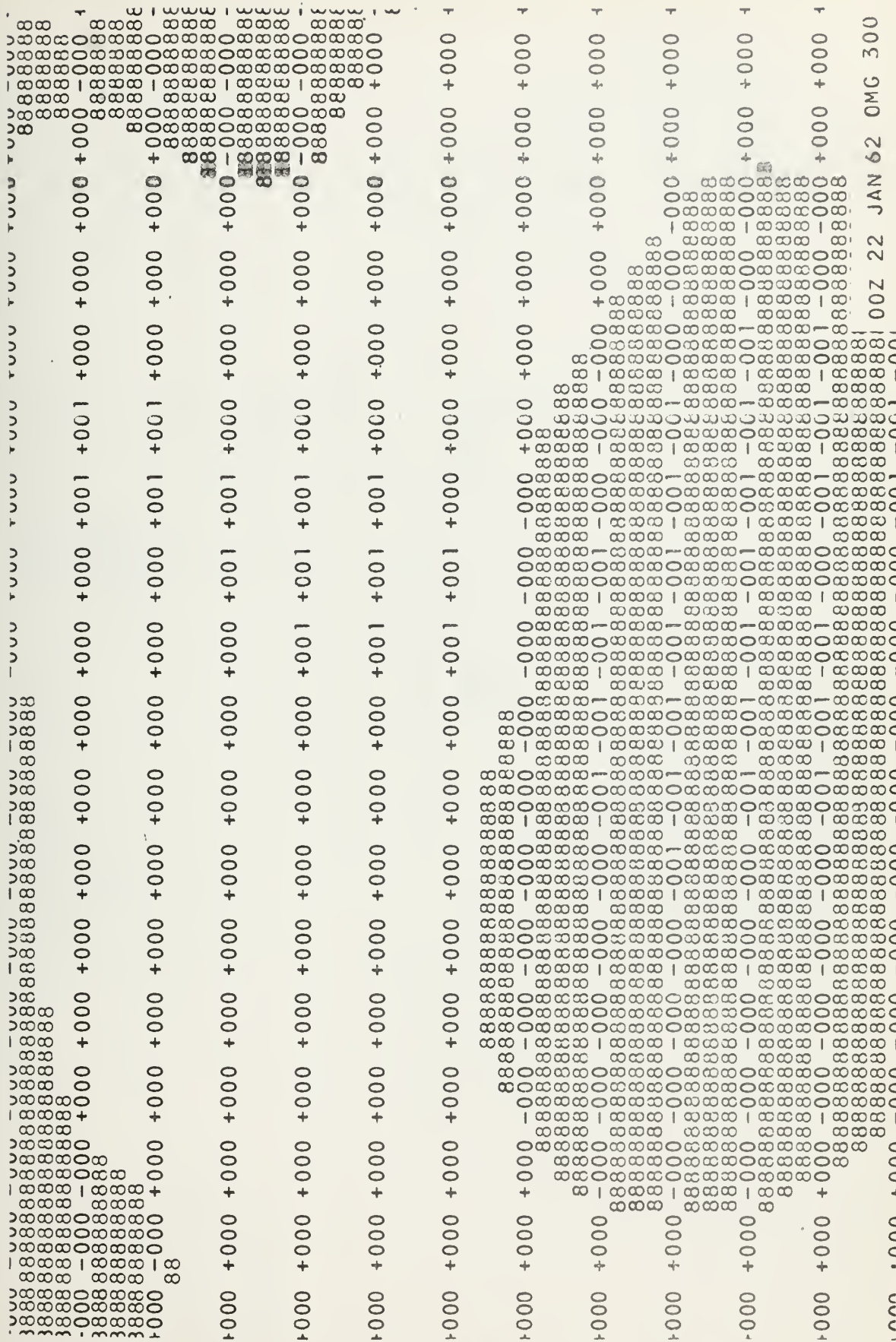


Figure 10. Ω at 300 mb with $\Omega_J = 0$.

7. Vertical-Velocity Computations for a Particular Synoptic Situation

The California snow storm of January, 1962 was selected to provide data for vertical-motion analyses. It was considered that this storm might provide results which would show the development of a situation which was inadequately forecast. An extensive synoptic investigation of this storm has been made by Ikegami [15].

The required input data of D values and temperatures at 1000, 850, 750, 500 and 300 mb were obtained from FNWF. Times chosen for analyses were 1200Z 17 January, 1200Z 20 January, 0000Z 21 January, 1200Z 21 January, 0000Z 22 January, 1200Z 22 January, 1200Z 23 January, and 1200Z 26 January.

Appendix A contains extracted portions of hemispheric prints which measure 30 x 26 inches. The extracts are the same scale as the originals. Since various cross sections are provided, a line delineating the cross section path is indicated. Also, grid points three and four are underlined. The Monterey Bay area lies between these two points, as shown by the continental outlines drawn on the chart on page 44 of Appendix A. This extract gives the pressure at terrain height for 0000Z 22 January. If it is desired to use the transparent overlay on these charts, shift the overlay to the left one grid point for proper display.

As indicated earlier, wherever terrain projected through any pressure level, the value +111 was printed at that grid point. For the maps provided, only the 850-mb level is affected. Since a point within the terrain was not relaxed in computing the omega fields, the terrain value of omega was substituted at that grid location.

The printed values of omega multiplied by 10^{-4} give units of mb/sec. Vorticity values multiplied by 10^{-6} give units of sec^{-1} .

a. Analysis for 17 January

(See Appendix A, pages 45 to 54 ; Appendix B, page 106)

In general, California was under the influence of subsidence associated with a high located to the west. However, in the northwestern United States a wave developed on a stationary front oriented from northwest to southeast. This wave continued to develop and the associated cold front brought heavy rains into California.

Rain began in the Monterey area about 1500Z 19 January and continued through 1300Z 20 January. Frontal passage occurred about 1000Z 20 January. The pressure rise was small and no appreciable increase in pressure was noted for 48 hours, due to a surface trough which remained in the area.

Program outputs of the region where this development occurred depict ascending air at all levels. Further, relative vorticity analyses show a maximum located northwest of the centers of rising air.

Appendix C, page 119, shows the presence of a blocking high at the 500-mb level. The block's orientation and the downstream cold low became the controlling factors in the movement of the surface wave.

b. Analysis for 20 January

(See Appendix A, pages 54 to 59 ; Appendix B, page 107 .)

By 1200Z the front had passed Monterey, but intermittent showers continued to about 1800Z. The center of ascending air was located northeast of the Monterey area with higher vertical velocities at the upper levels. Strong subsidence to the northwest was apparently moving eastward and would soon dominate the local weather.

But, as seen in Appendix C, page 121, the previously-mentioned block was now fully developed. The downstream low became quasi-stationary and

the area of subsidence remained to the west.

c. Analysis for 21 January

(See Appendix A, pages 59 to 77; Appendix B, pages 108 to 110.)

The 500-mb chart for 0000Z (Appendix C, page 128) shows essentially the same situation as existed 12 hours earlier. The temperature of the cold low was near -40C. Moreover, this tongue of cold air extended down to the 1000-mb level. However, the ascending air was now located south-east of Monterey, and higher vertical velocities were found at lower levels.

The 1200Z analyses show that the center of maximum relative vorticity and ascending air were coincident at low levels, i.e., through 850 mb. Using the terrain boundary on the 850-mb chart, it appears that topography restrained the lower portion of the rising column, shearing it from the main cell.

Rain commenced locally at 0600Z 21 January. Snow pellets began falling about 1400Z and snow showers began at 1615Z. Throughout the period ending 1000Z 22 January, snow showers, snow pellets and rain were frequent.

d. Analysis for 22 January

(See Appendix A, pages 77 to 95; Appendix B, pages 110 to 115.)

The significant aspect at 0000Z was the change in direction of movement of the cell of rising air to the southwest. Vertical velocities decreased near points three and four at the 850-mb surface. Appendix C, pages 136, 139, and 142, shows the extent of low-level instability. However, to the west, subsidence was clearly increasing at all levels and now appeared to be moving to the east.

The 1200Z results show further movement and intensification of

subsidence as it proceeded into northern California. The ascending air continued moving southwestward. The surface low, after having reached a position in southeastern Nevada, moved southwest and weakened west of Lower California. At 1200Z 22 January, it was situated over the Los Angeles area.

e. Analysis for 23 January

(See Appendix A, pages 95 to 100; Appendix B, page 115)

These 1200Z charts, 24 hours later than the previous analyses, show points three and four were under the direct influence of descending motion, save for a small area of rising air due to terrain effects near point four. The velocity of the ascending air to the southeast generally decreased and the cell appeared to be weakening.

In Appendix C, pages 146 to 156, the shift of cold temperatures and the trough towards the southwest and the weakening of the block at 500 mb are depicted.

f. Analysis for 26 January

(See Appendix A, pages 100 to 105; Appendix B, page 116.)

The entire West Coast was under the influence of subsidence and little evidence remained of the column of rising air. Appendix C, page 157, shows the trough had resumed normal west-to-east movement.

g. Conclusions

The preceding analyses suggest that had this vertical velocity data been available, the forecast of fair and sunny conditions for 21 January would not have been issued. The vertical motion fields, together with temperature analyses, indicate the impending storm.

The omega fields were compared to the surface analyses as transmitted by facsimile, and indicate that the direction of vertical motion

might have been inferred from conventional map analyses alone. However, the magnitude of the velocities of ascending air in the surface trough could hardly have been appreciated from such maps.

Lack of time precluded computing vertical velocities for other synoptic situations. Also, as interesting and encouraging as these indications are, it should further be pointed out that the results displayed are for an area of abundant data. It remains to be seen how useful and accurate vertical-velocity computations are in areas of sparse upper-air data.

The outputs of this program can form the basis for other investigations in the field of numerical forecasting. Presently, the vertical velocities obtained here are being used to compute the transformation of potential energy to kinetic energy on a hemispheric scale.

With prognostic D and temperature fields, prognostic vertical motions can be computed. The addition of hemispheric dew-point analyses and prediction would permit forecasts of cloudiness and precipitation. The contribution of the release of latent heat to the stability parameter could then be included. The obvious application of the omega fields to a multi-level forecast model is another possibility.

On the hemispheric charts, numerical shading between plus and minus areas of vertical motion imparted an appearance of cloud patterns. Since facsimiles of TIROS IV cloud pictures were available, two samples were chosen for comparison.

Appendix D contains the TIROS pictures and the applicable omega fields. Page 159 is the 0501Z 17 May 1962 TIROS observation; an apparent vortex is indicated near 35N 163E. Here the vertical motion charts lag the observation by seven hours.

Page 165 is a 2220Z 29 May 1962 picture. A vortex is located near 42N 100W. The omega charts are for a period about two hours later.

The observations and representations are well correlated. Perhaps further study would enable the cloud type to be correlated with the vertical-velocity field with respect to sign, magnitude, and level.

APPENDIX A

EXTRACTS FROM HEMISPHERIC PRINTS OF
OMEGA AND RELATIVE VORTICITY FIELDS

[illegible]

[illegible]

127 17 JAN 62 RV 850

127 17 JAN 62 RV

50

50

50

[illegible]

[illegible]

[illegible]

[illegible]

001	002	003	004	005	006	007	008	009	010	011	012	013	014	015	016	017	018	019	020	021	022	023	024	025	026	027	028	029	030	031	032	033	034	035	036	037	038	039	040	041	042	043	044	045	046	047	048	049	050	051	052	053	054	055	056	057	058	059	060	061	062	063	064	065	066	067	068	069	070	071	072	073	074	075	076	077	078	079	080	081	082	083	084	085	086	087	088	089	090	091	092	093	094	095	096	097	098	099	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379	380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	400	401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416	417	418	419	420	421	422	423	424	425	426	427	428	429	430	431	432	433	434	435	436	437	438	439	440	441	442	443	444	445	446	447	448	449	450	451	452	453	454	455	456	457	458	459	460	461	462	463	464	465	466	467	468	469	470	471	472	473	474	475	476	477	478	479	480	481	482	483	484	485	486	487	488	489	490	491	492	493	494	495	496	497	498	499	500	501	502	503	504	505	506	507	508	509	510	511
-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

002 1

JAN 62 R1

00883 007 21

THE

[illegible][illegible][illegible]

0000000000

00 00

[illegible]

[illegible]

[illegible]

[illegible]

12Z 21 JAN 62 OMEGALO

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

12Z 21 JAN 62 DMG 500

○ ○ ○
○ ○ ○
○ ○ ○
○ ○ ○
○ ○ ○
○ ○ ○
○ ○ ○
○ ○ ○

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

001 002 003 004 005 006 007 008 009 010 011 012 013 014 015 016 017 018 019 020 021 022 023 024 025 026 027 028 029 030 031 032 033 034 035 036 037 038 039 040 041 042 043 044 045 046 047 048 049 050 051 052 053 054 055 056 057 058 059 060 061 062 063 064 065 066 067 068 069 070 071 072 073 074 075 076 077 078 079 080 081 082 083 084 085 086 087 088 089 090 091 092 093 094 095 096 097 098 099 100 101 102 103 104 105 106 107 108 109 110 111 112 113 114 115 116 117 118 119 120 121 122 123 124 125 126 127 128 129 130 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167 168 169 170 171 172 173 174 175 176 177 178 179 180 181 182 183 184 185 186 187 188 189 190 191 192 193 194 195 196 197 198 199 200 201 202 203 204 205 206 207 208 209 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224 225 226 227 228 229 230 231 232 233 234 235 236 237 238 239 240 241 242 243 244 245 246 247 248 249 250 251 252 253 254 255 256 257 258 259 260 261 262 263 264 265 266 267 268 269 270 271 272 273 274 275 276 277 278 279 280 281 282 283 284 285 286 287 288 289 290 291 292 293 294 295 296 297 298 299 300 301 302 303 304 305 306 307 308 309 310 311 312 313 314 315 316 317 318 319 320 321 322 323 324 325 326 327 328 329 330 331 332 333 334 335 336 337 338 339 340 341 342 343 344 345 346 347 348 349 350 351 352 353 354 355 356 357 358 359 360 361 362 363 364 365 366 367 368 369 370 371 372 373 374 375 376 377 378 379 380 381 382 383 384 385 386 387 388 389 390 391 392 393 394 395 396 397 398 399 400 401 402 403 404 405 406 407 408 409 410 411 412 413 414 415 416 417 418 419 420 421 422 423 424 425 426 427 428 429 430 431 432 433 434 435 436 437 438 439 440 441 442 443 444 445 446 447 448 449 450 451 452 453 454 455 456 457 458 459 460 461 462 463 464 465 466 467 468 469 470 471 472 473 474 475 476 477 478 479 480 481 482 483 484 485 486 487 488 489 490 491 492 493 494 495 496 497 498 499 500 501 502 503 504 505 506 507 508 509 510 511 512 513 514 515 516 517 518 519 520 521 522 523 524 525 526 527 528 529 530 531 532 533 534 535 536 537 538 539 540 541 542 543 544 545 546 547 548 549 550 551 552 553 554 555 556 557 558 559 560 561 562 563 564 565 566 567 568 569 570 571 572 573 574 575 576 577 578 579 580 581 582 583 584 585 586 587 588 589 590 591 592 593 594 595 596 597 598 599 600 601 602 603 604 605 606 607 608 609 610 611 612 613 614 615 616 617 618 619 620 621 622 623 624 625 626 627 628 629 630 631 632 633 634 635 636 637 638 639 640 641 642 643 644 645 646 647 648 649 650 651 652 653 654 655 656 657 658 659 660 661 662 663 664 665 666 667 668 669 670 671 672 673 674 675 676 677 678 679 680 681 682 683 684 685 686 687 688 689 690 691 692 693 694 695 696 697 698 699 700 701 702 703 704 705 706 707 708 709 710 711 712 713 714 715 716 717 718 719 720 721 722 723 724 725 726 727 728 729 730 731 732 733 734 735 736 737 738 739 740 741 742 743 744 745 746 747 748 749 750 751 752 753 754 755 756 757 758 759 760 761 762 763 764 765 766 767 768 769 770 771 772 773 774 775 776 777 778 779 780 781 782 783 784 785 786 787 788 789 790 791 792 793 794 795 796 797 798 799 800 801 802 803 804 805 806 807 808 809 810 811 812 813 814 815 816 817 818 819 820 821 822 823 824 825 826 827 828 829 830 831 832 833 834 835 836 837 838 839 840 841 842 843 844 845 846 847 848 849 850 851 852 853 854 855 856 857 858 859 860 861 862 863 864 865 866 867 868 869 870 871 872 873 874 875 876 877 878 879 880 881 882 883 884 885 886 887 888 889 890 891 892 893 894 895 896 897 898 899 900 901 902 903 904 905 906 907 908 909 910 911 912 913 914 915 916 917 918 919 920 921 922 923 924 925 926 927 928 929 930 931 932 933 934 935 936 937 938 939 940 941 942 943 944 945 946 947 948 949 950 951 952 953 954 955 956 957 958 959 960 961 962 963 964 965 966 967 968 969 970 971 972 973 974 975 976 977 978 979 980 981 982 983 984 985 986 987 988 989 990 991 992 993 994 995 996 997 998 999 1000

00Z 22 JAN 62 RV 700

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

12Z 22 JAN 82 QMG 850

00 00 1
00 00
00 00 0
00 00 C
00 00 C
00 00 1
00 00

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

127 23 JAN 62 OMEGALO

100

0001	0002	0003	0004	0005	0006	0007	0008	0009	0010	0011	0012	0013	0014	0015	0016	0017	0018	0019	0020	0021	0022	0023	0024	0025	0026	0027	0028	0029	0030	0031	0032	0033	0034	0035	0036	0037	0038	0039	0040	0041	0042	0043	0044	0045	0046	0047	0048	0049	0050	0051	0052	0053	0054	0055	0056	0057	0058	0059	0060	0061	0062	0063	0064	0065	0066	0067	0068	0069	0070	0071	0072	0073	0074	0075	0076	0077	0078	0079	0080	0081	0082	0083	0084	0085	0086	0087	0088	0089	0090	0091	0092	0093	0094	0095	0096	0097	0098	0099	0100	0101	0102	0103	0104	0105	0106	0107	0108	0109	0110	0111	0112	0113	0114	0115	0116	0117	0118	0119	0120	0121	0122	0123	0124	0125	0126	0127	0128	0129	0130	0131	0132	0133	0134	0135	0136	0137	0138	0139	0140	0141	0142	0143	0144	0145	0146	0147	0148	0149	0150	0151	0152	0153	0154	0155	0156	0157	0158	0159	0160	0161	0162	0163	0164	0165	0166	0167	0168	0169	0170	0171	0172	0173	0174	0175	0176	0177	0178	0179	0180	0181	0182	0183	0184	0185	0186	0187	0188	0189	0190	0191	0192	0193	0194	0195	0196	0197	0198	0199	0200	0201	0202	0203	0204	0205	0206	0207	0208	0209	0210	0211	0212	0213	0214	0215	0216	0217	0218	0219	0220	0221	0222	0223	0224	0225	0226	0227	0228	0229	0230	0231	0232	0233	0234	0235	0236	0237	0238	0239	0240	0241	0242	0243	0244	0245	0246	0247	0248	0249	0250	0251	0252	0253	0254	0255	0256	0257	0258	0259	0260	0261	0262	0263	0264	0265	0266	0267	0268	0269	0270	0271	0272	0273	0274	0275	0276	0277	0278	0279	0280	0281	0282	0283	0284	0285	0286	0287	0288	0289	0290	0291	0292	0293	0294	0295	0296	0297	0298	0299	0300	0301	0302	0303	0304	0305	0306	0307	0308	0309	0310	0311	0312	0313	0314	0315	0316	0317	0318	0319	0320	0321	0322	0323	0324	0325	0326	0327	0328	0329	0330	0331	0332	0333	0334	0335	0336	0337	0338	0339	0340	0341	0342	0343	0344	0345	0346	0347	0348	0349	0350	0351	0352	0353	0354	0355	0356	0357	0358	0359	0360	0361	0362	0363	0364	0365	0366	0367	0368	0369	0370	0371	0372	0373	0374	0375	0376	0377	0378	0379	0380	0381	0382	0383	0384	0385	0386	0387	0388	0389	0390	0391	0392	0393	0394	0395	0396	0397	0398	0399	0400	0401	0402	0403	0404	0405	0406	0407	0408	0409	0410	0411	0412	0413	0414	0415	0416	0417	0418	0419	0420	0421	0422	0423	0424	0425	0426	0427	0428	0429	0430	0431	0432	0433	0434	0435	0436	0437	0438	0439	0440	0441	0442	0443	0444	0445	0446	0447	0448	0449	0450	0451	0452	0453	0454
------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------

12Z 23 JAN 62 QMG 850

UT 500T

002	001	002	003	004	005	006	007	008	009	010	011	012	013	014	015	016	017	018	019	020	021	022	023	024	025	026	027	028	029	030	031	032	033	034	035	036	037	038	039	040	041	042	043	044	045	046	047	048	049	050	051	052	053	054	055	056	057	058	059	060	061	062	063	064	065	066	067	068	069	070	071	072	073	074	075	076	077	078	079	080	081	082	083	084	085	086	087	088	089	090	091	092	093	094	095	096	097	098	099	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379	380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	400	401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416	417	418	419	420	421	422	423	424	425	426	427	428	429	430	431	432	433	434	435	436	437	438	439	440	441	442	443	444	445	446	447	448	449	450	451	452	453	454	455	456	457	458	459	460	461	462	463	464	465	466	467	468	469	470	471	472	473	474	475	476	477	478	479	480	481	482	483	484	485	486	487	488	489	490	491	492	493	494	495	496	497	498	499	500	501	502	503	504	505	506	507	508	509	510
-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----

[illegible][illegible]

[illegible][illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

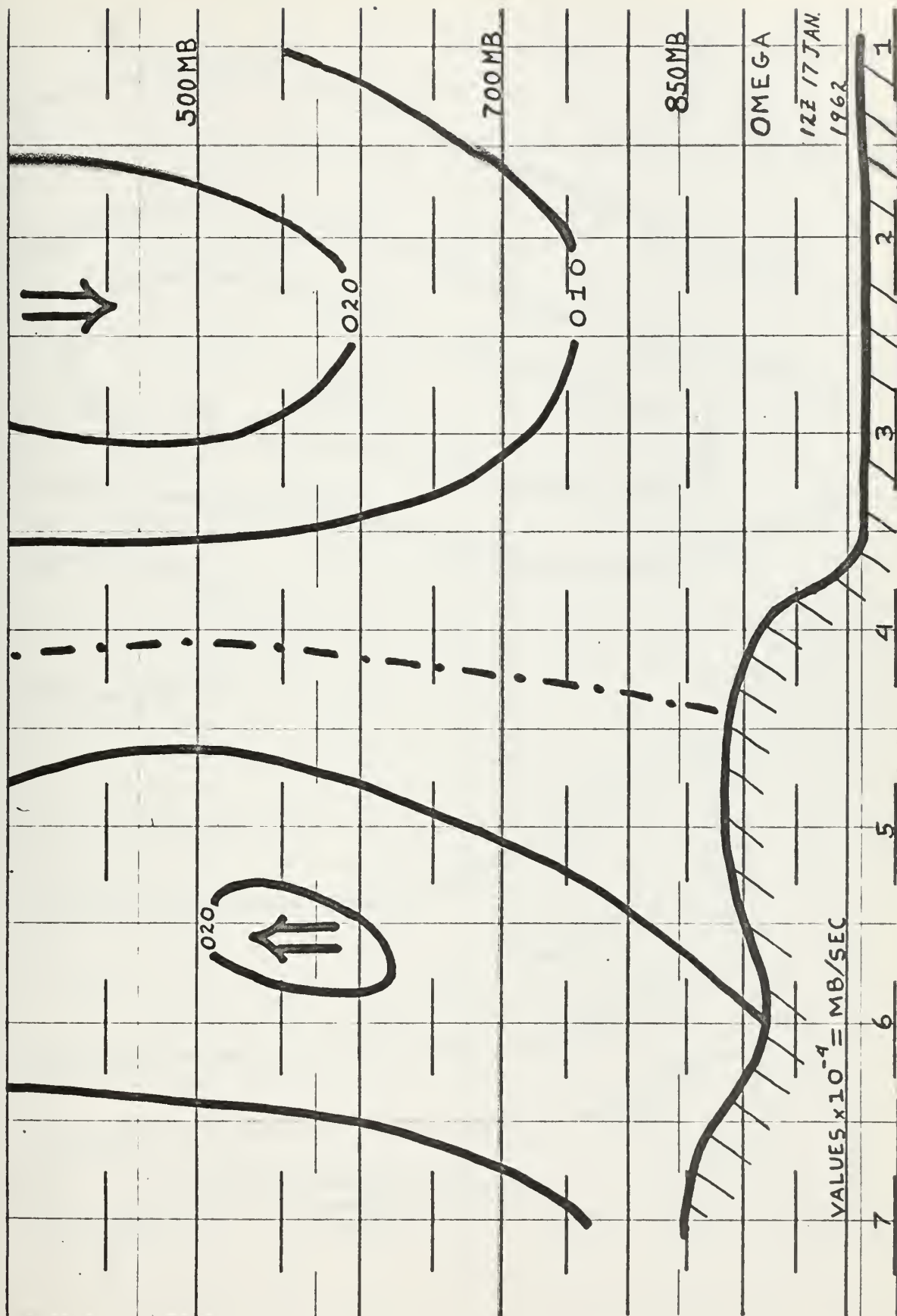
12Z 26 JAN 62 OMG 300

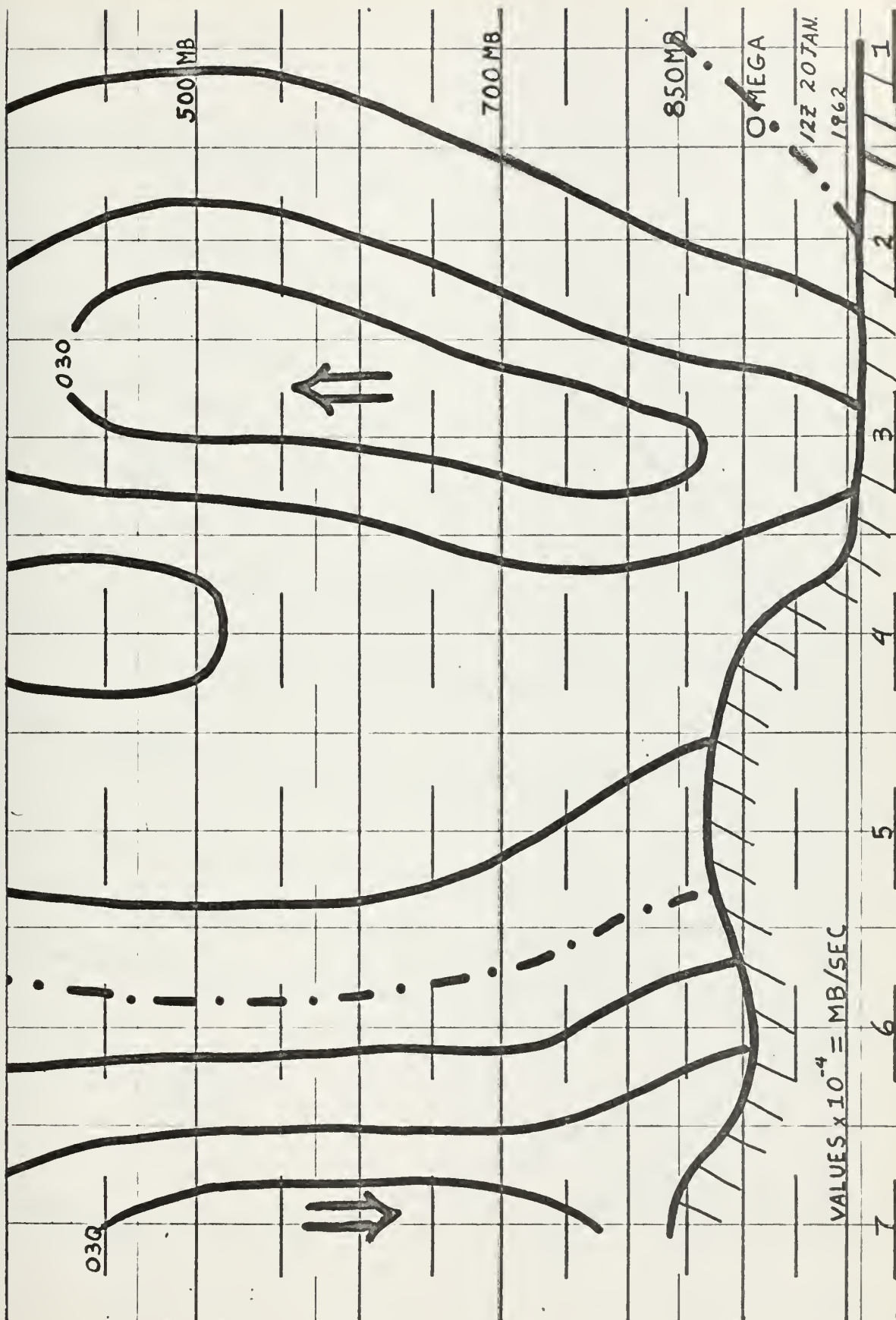
[illegible]

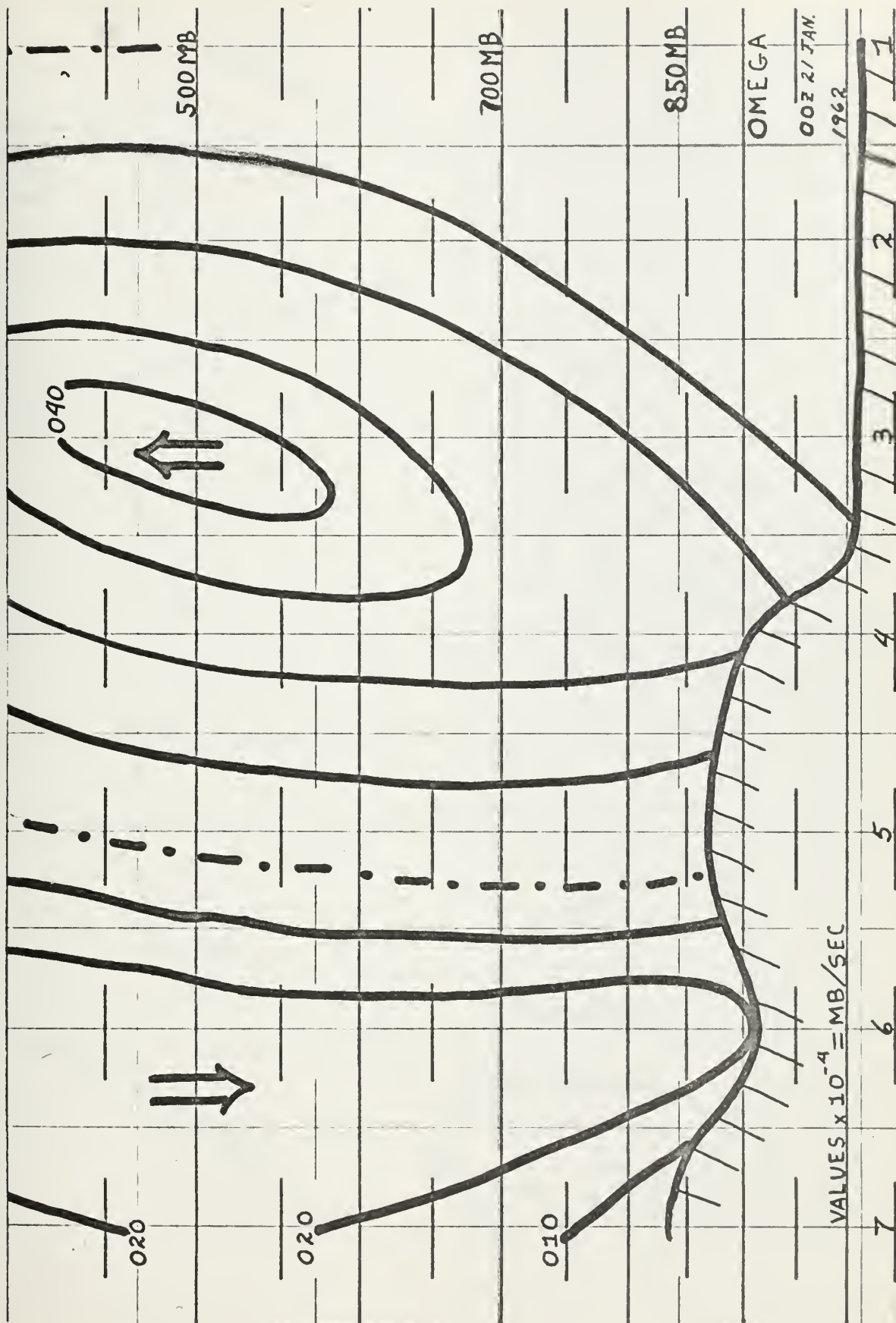
APPENDIX B

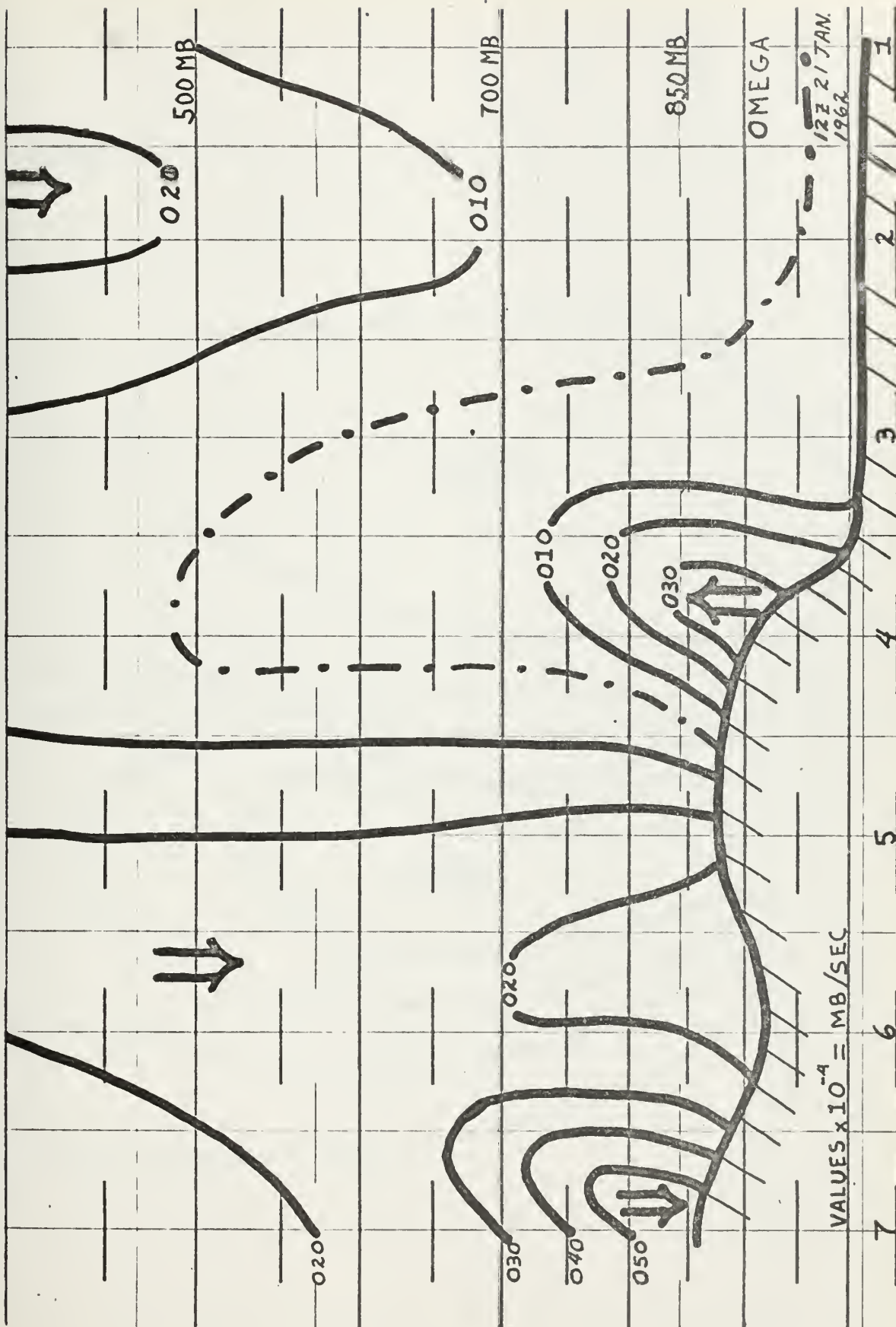
CROSS SECTIONS OF OMEGA FIELDS
PLUS TEMPERATURE, RELATIVE VORTICITY AND STABILITY
FOR 0000Z 22 JANUARY 1962

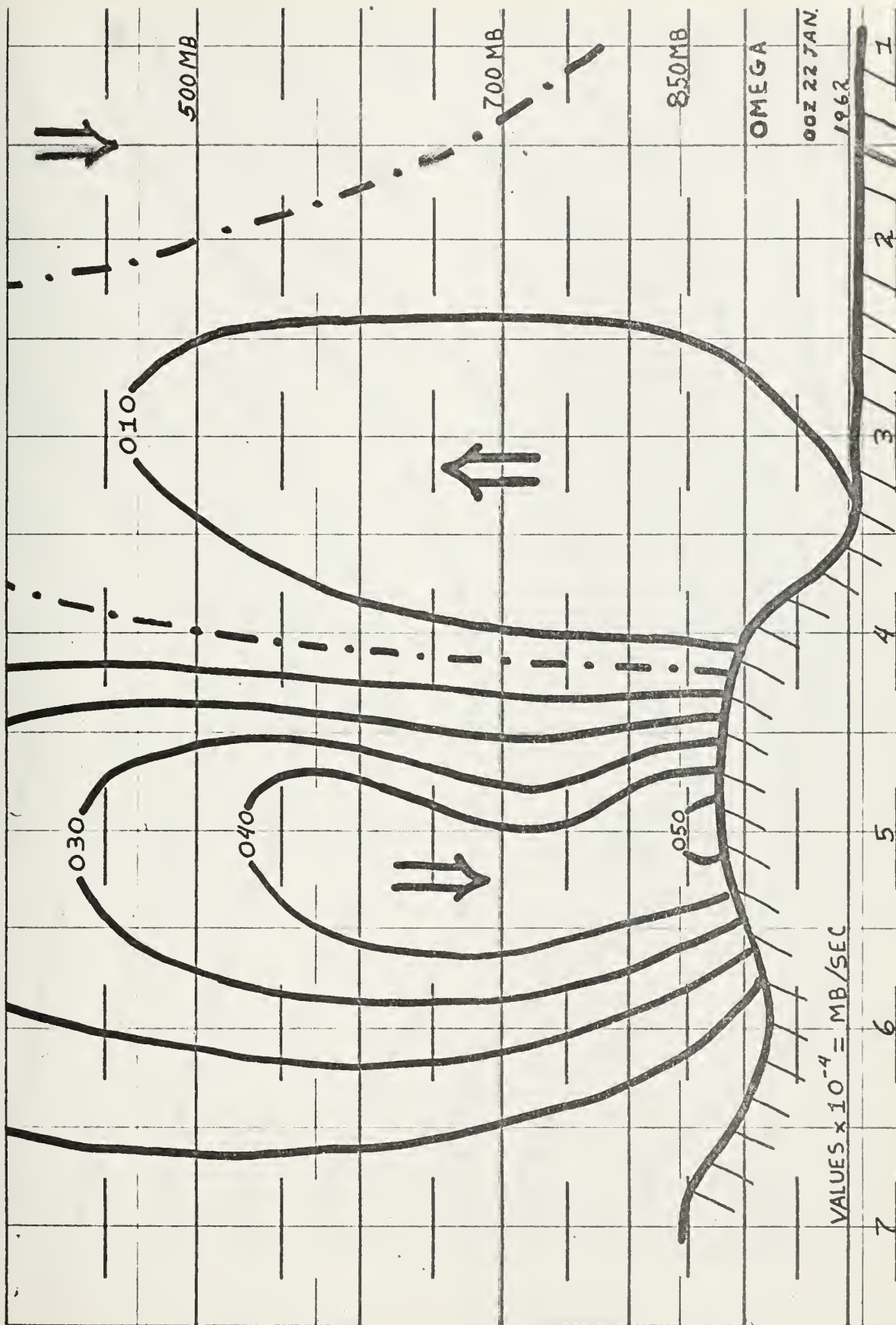
(DOT-DASH LINE IS A ZERO LINE.)

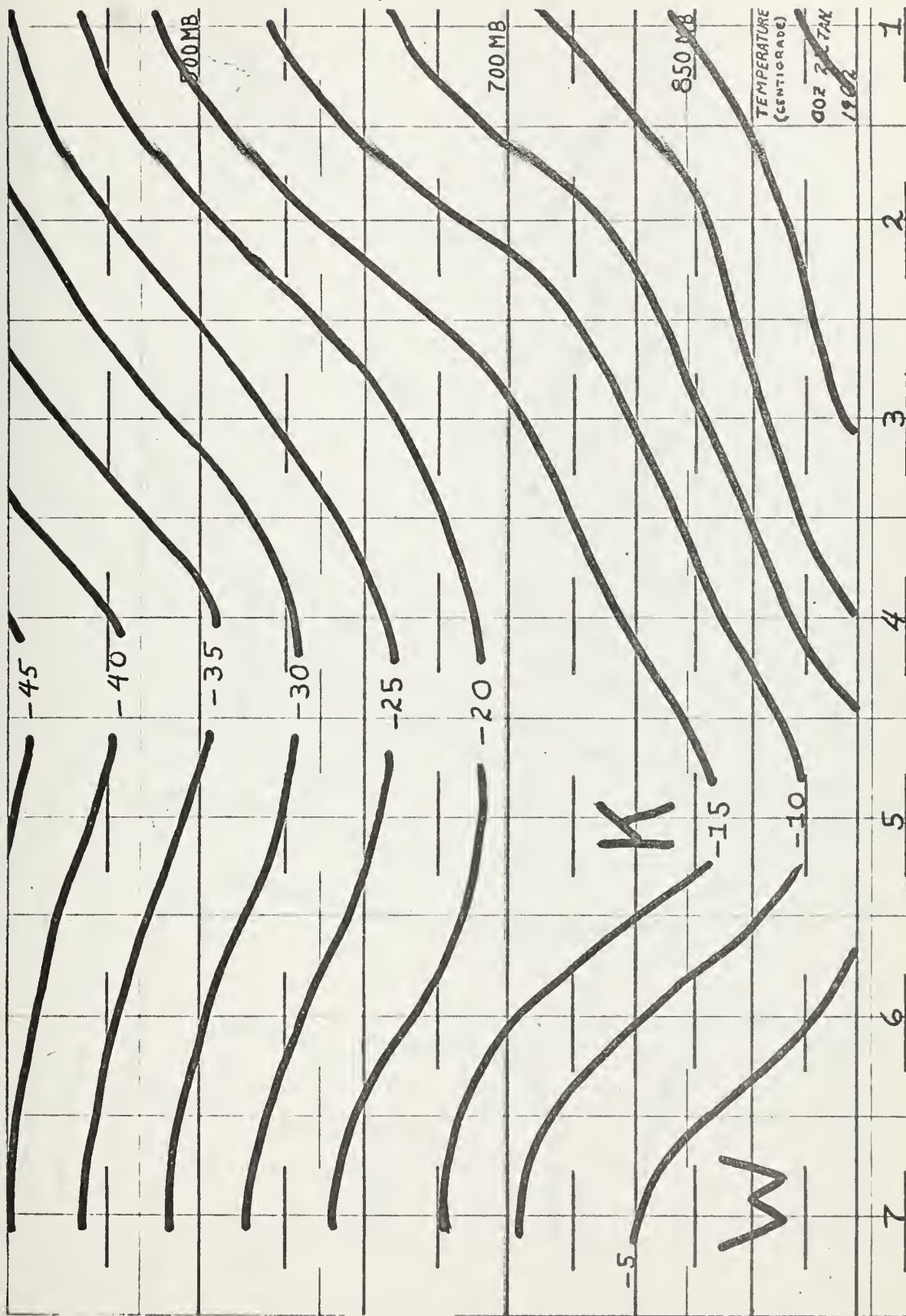


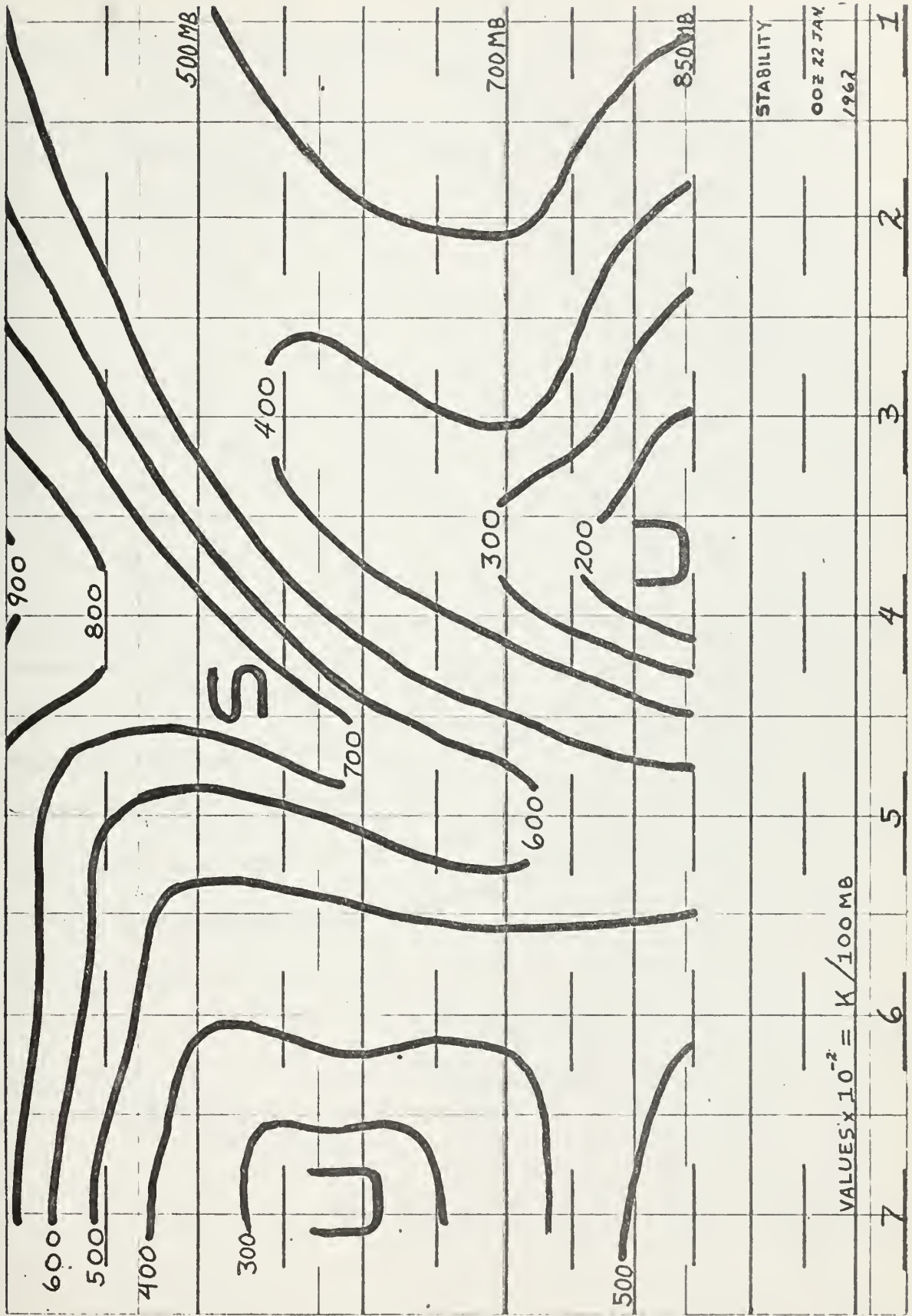


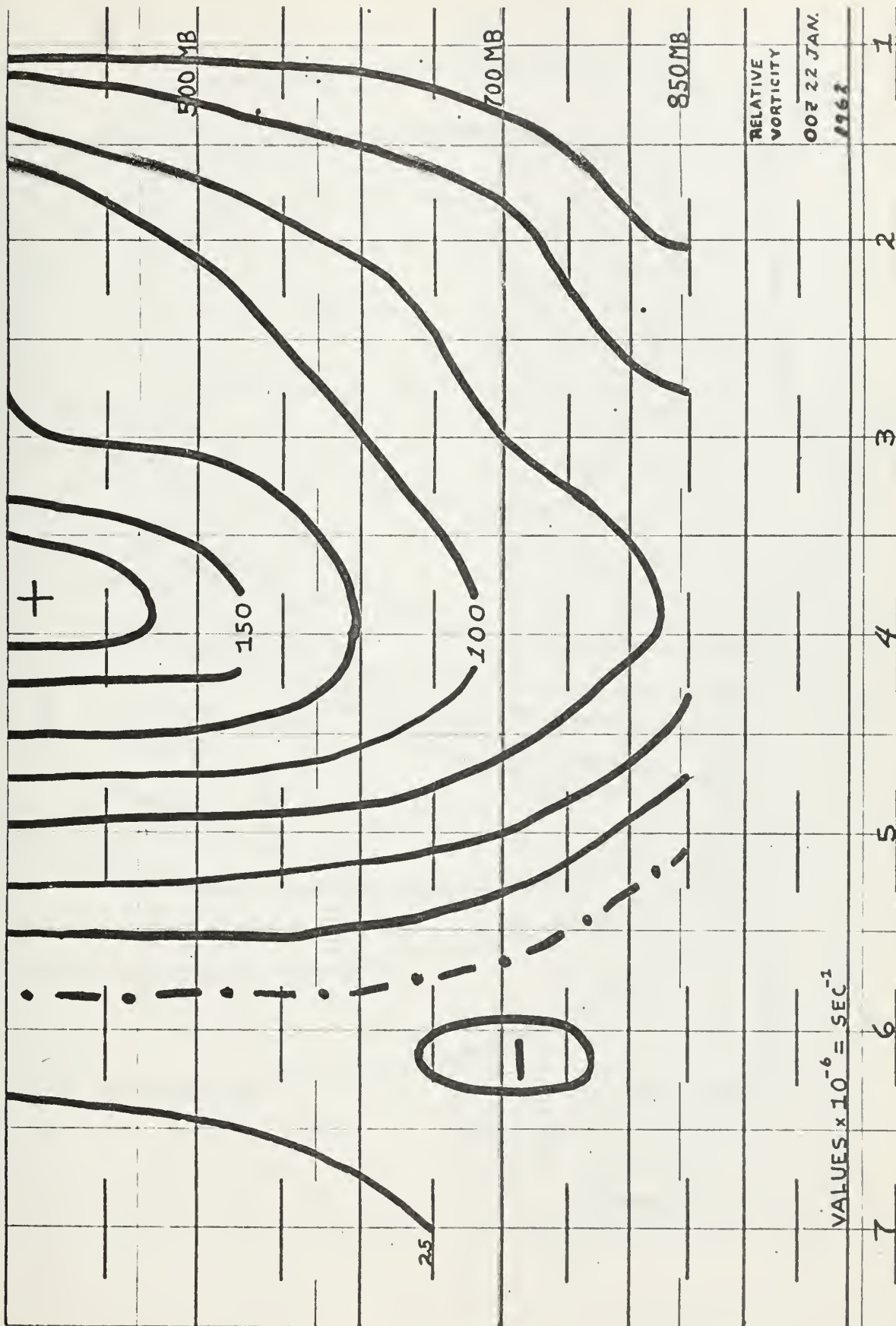


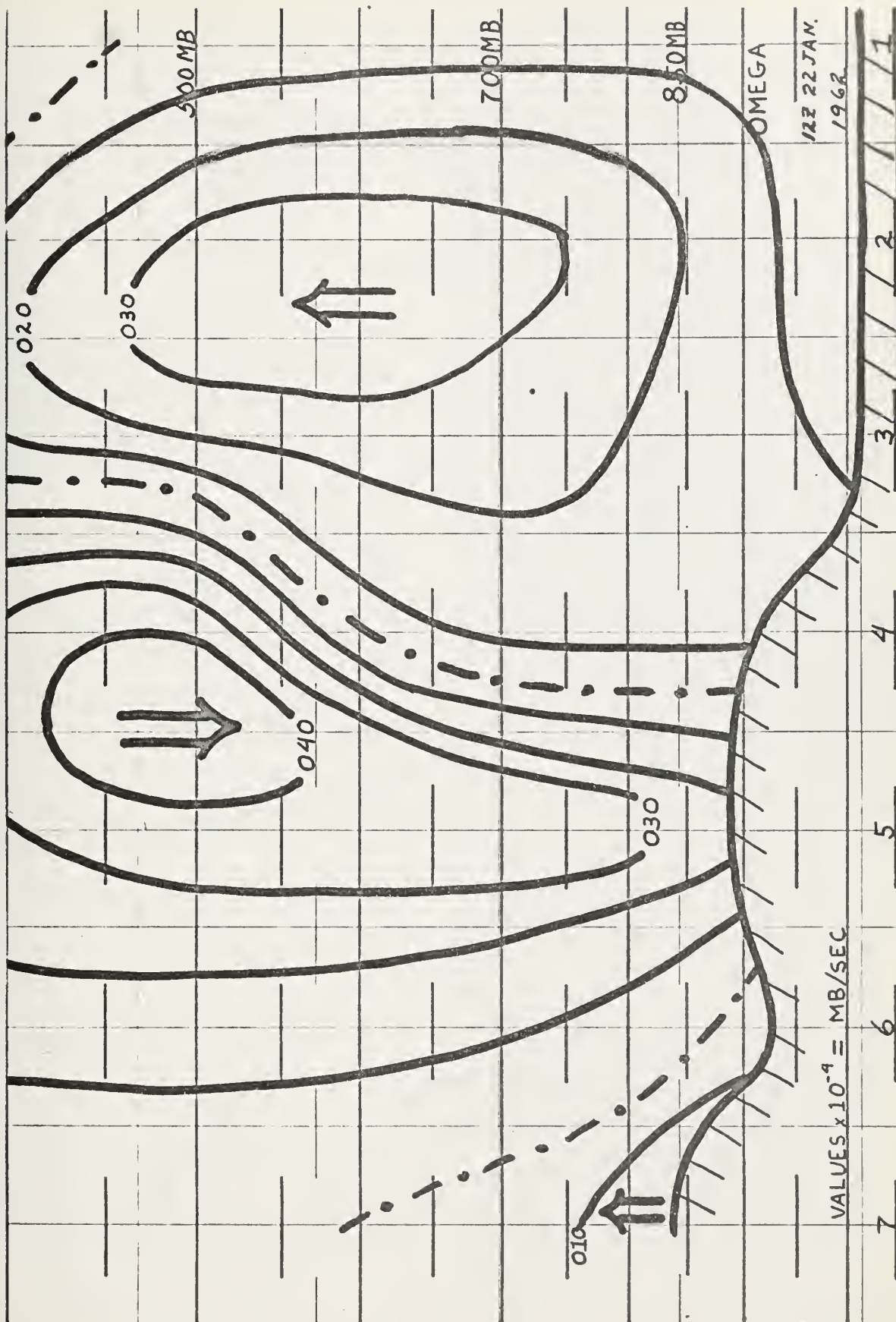


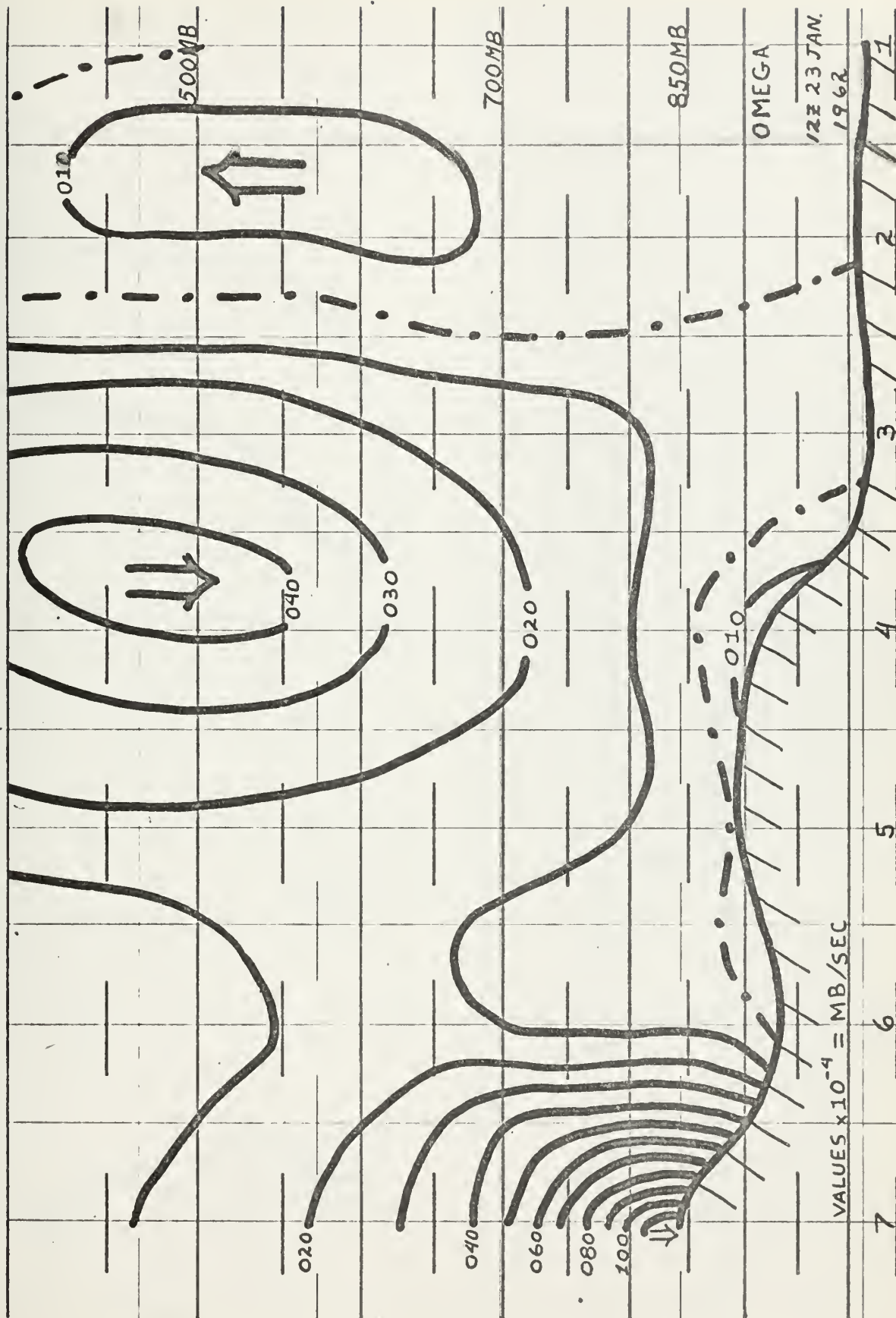


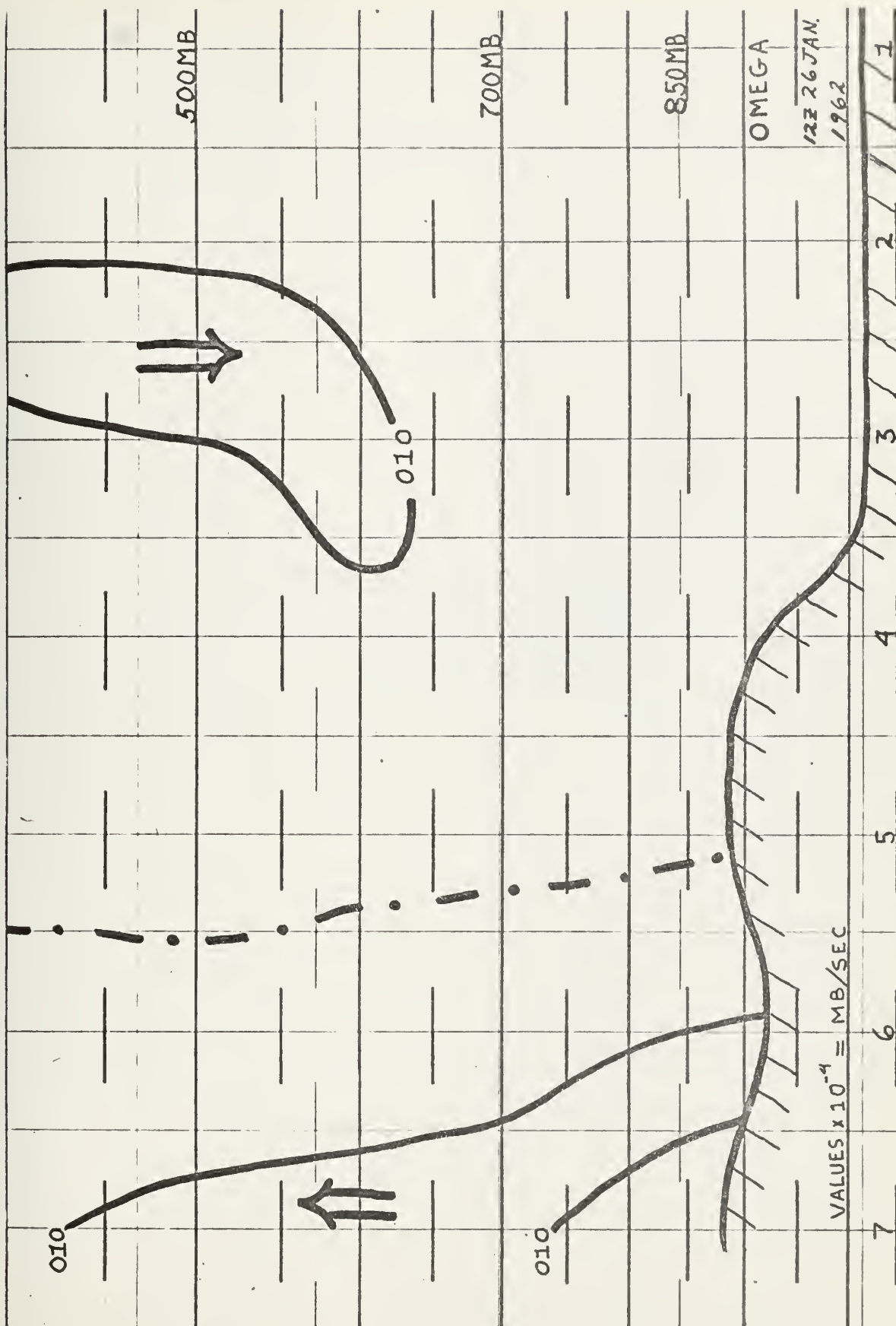








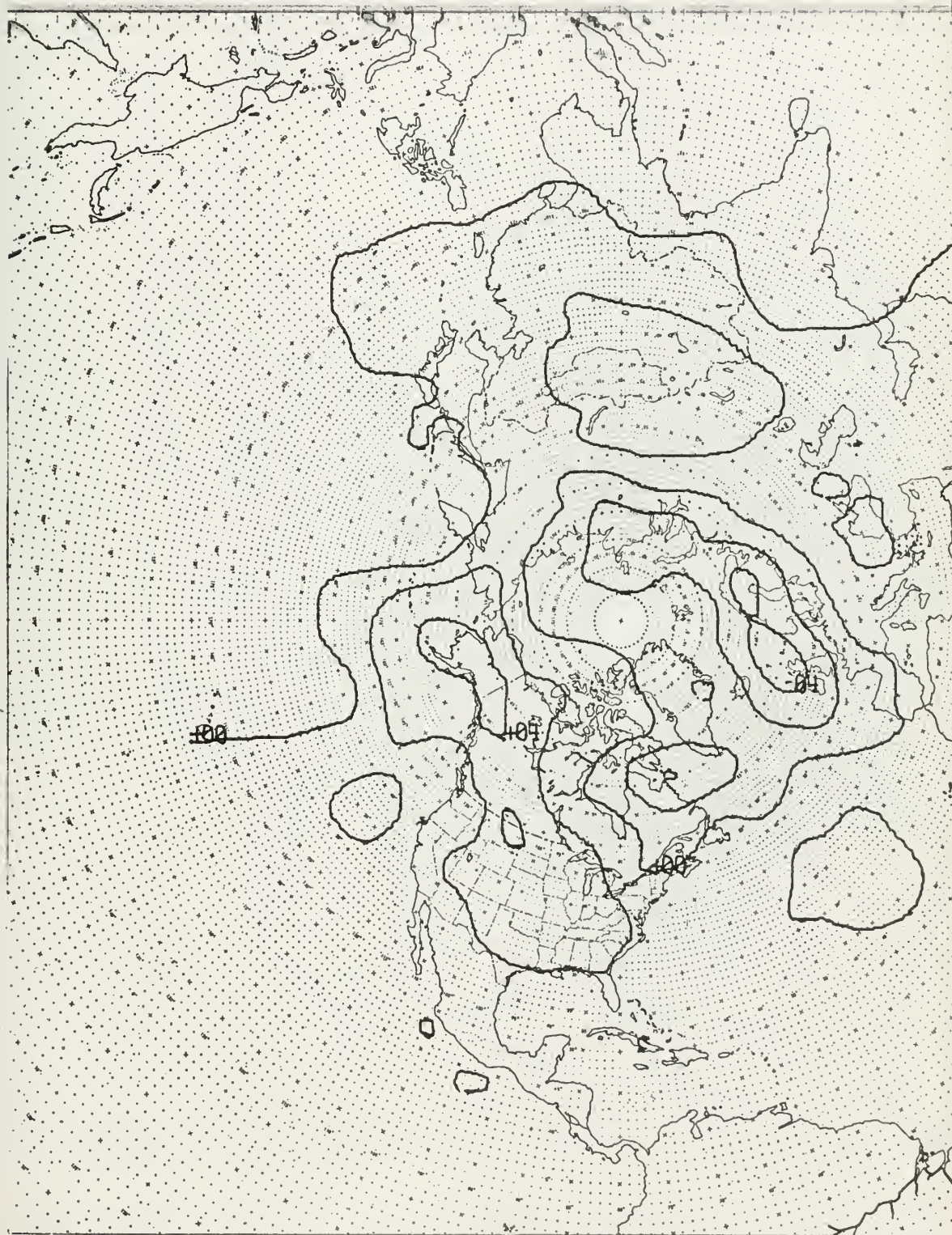




APPENDIX C

HEMISPHERIC CHARTS OF D VALUES
AND TEMPERATURES PLUS STABILITY
FOR 0000Z 22 JANUARY 1962

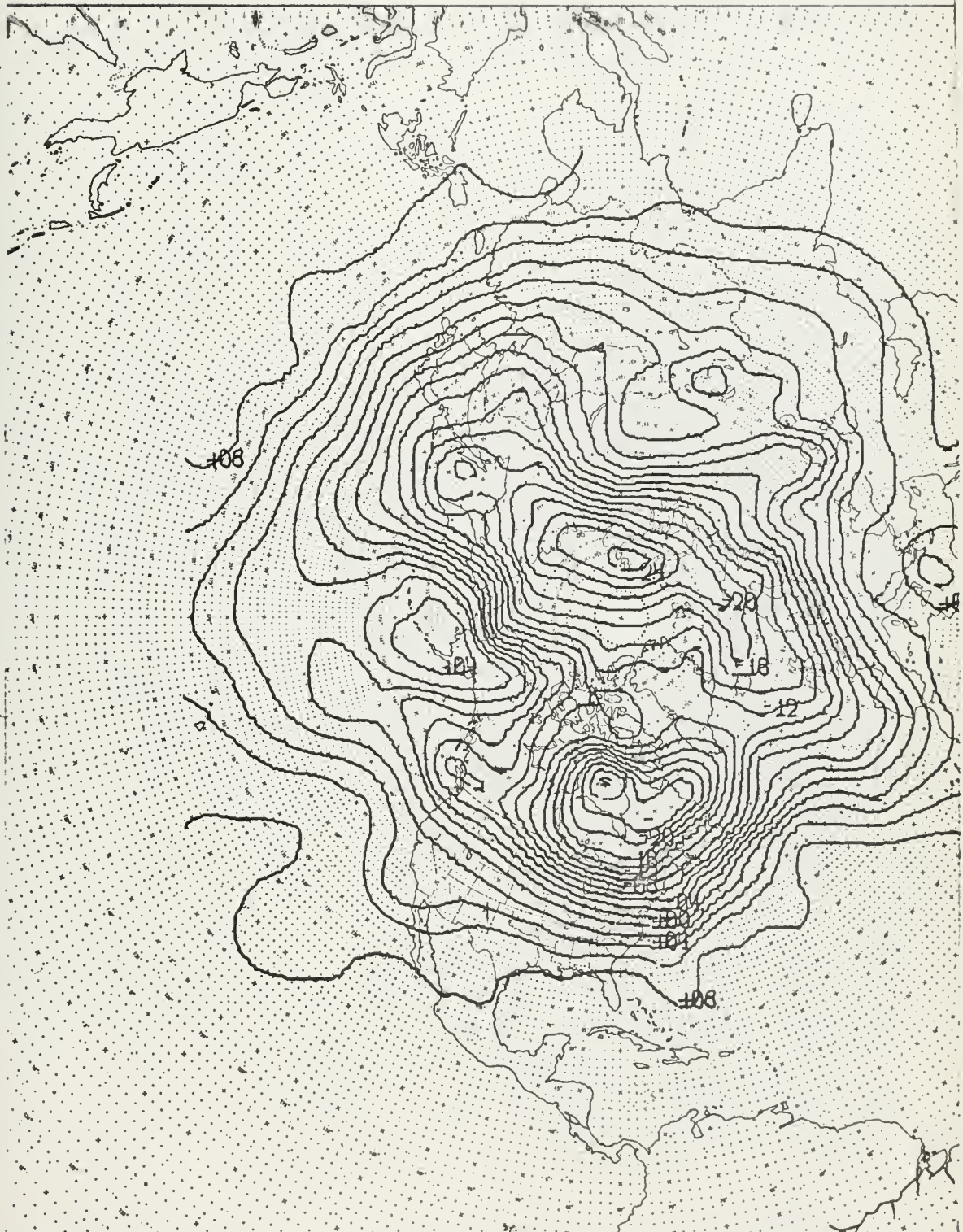
12Z 17 JAN 62 D 1000



SCALE: 1:120,000,000

FLEET NUMERICAL WEATHER FACILITY, MONTEREY, CALIFORNIA

12Z 17 JAN 62 D 500



SCALE: 1:120,000,000

FLEET NUMERICAL WEATHER FACILITY, MONTEREY, CALIFORNIA

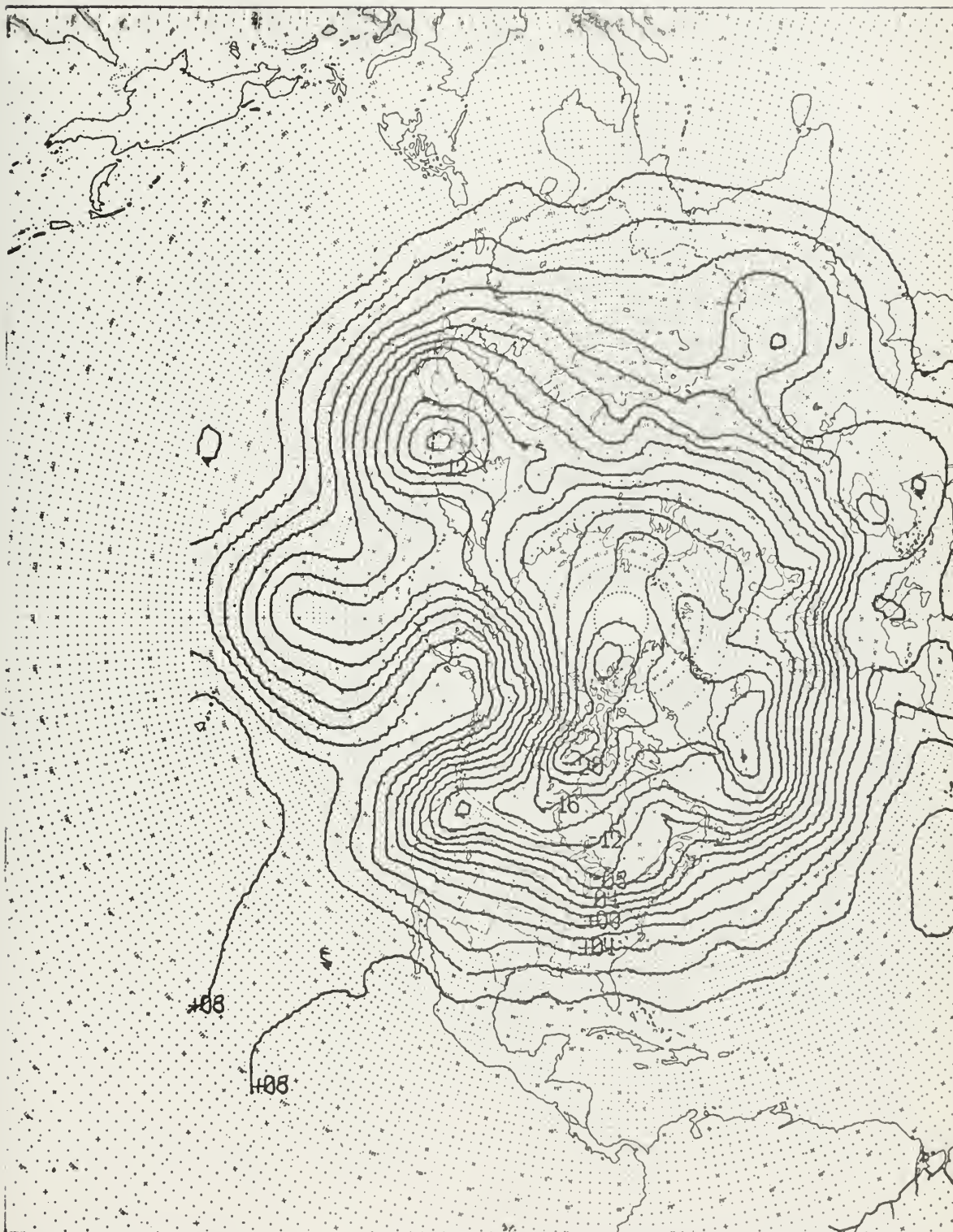
12Z 20 JAN 62 D 1000



SCALE: 1:120,000,000

FLEET NUMERICAL WEATHER FACILITY, MONTEREY, CALIFORNIA

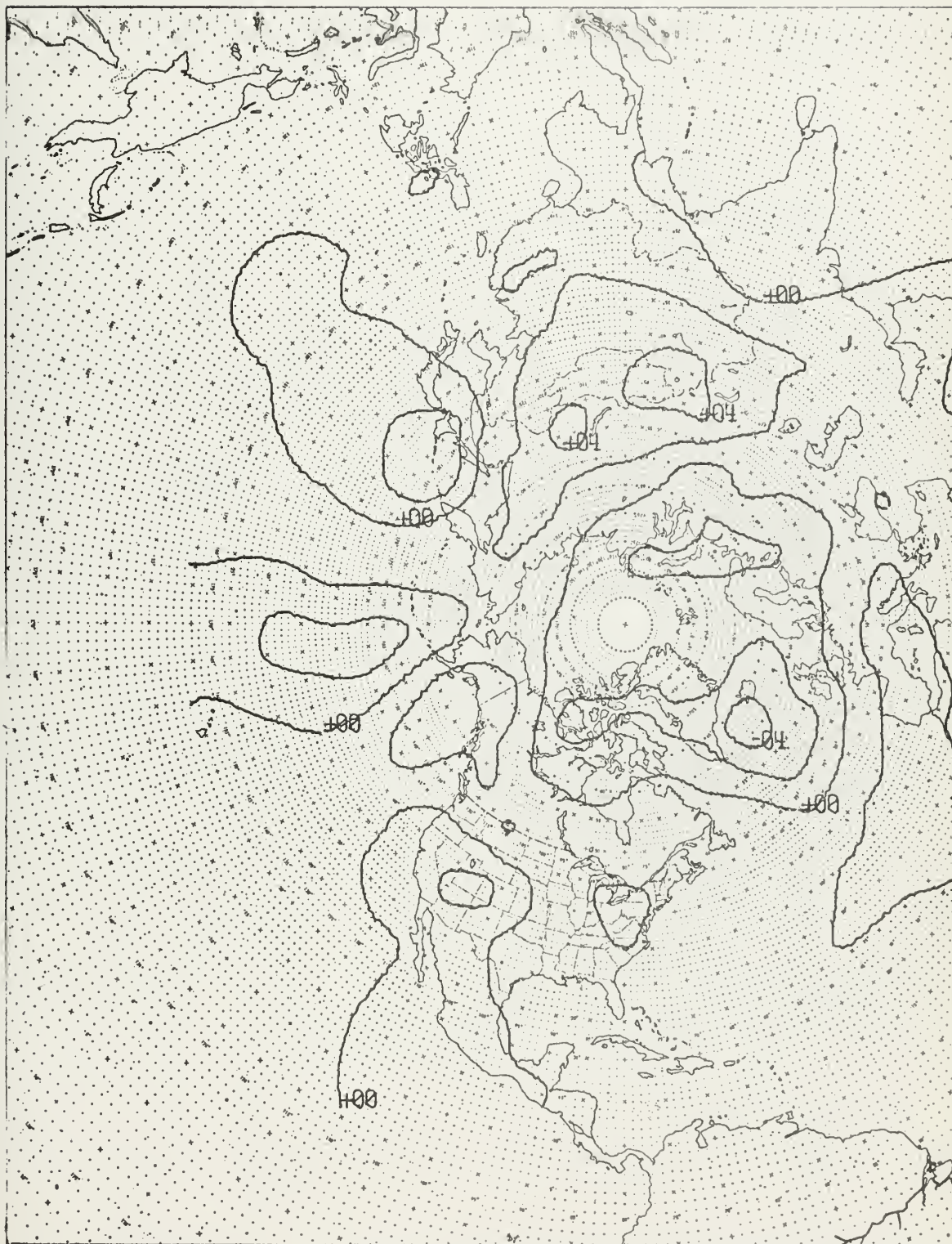
12Z 20 JAN 62 D 500



SCALE: 1:120,000,000

FLEET NUMERICAL WEATHER FACILITY, MONTEREY, CALIFORNIA

00Z 21 JAN 62 D 1000



SCALE: 1:120,000,000

FLEET NUMERICAL WEATHER FACILITY, MONTEREY, CALIFORNIA

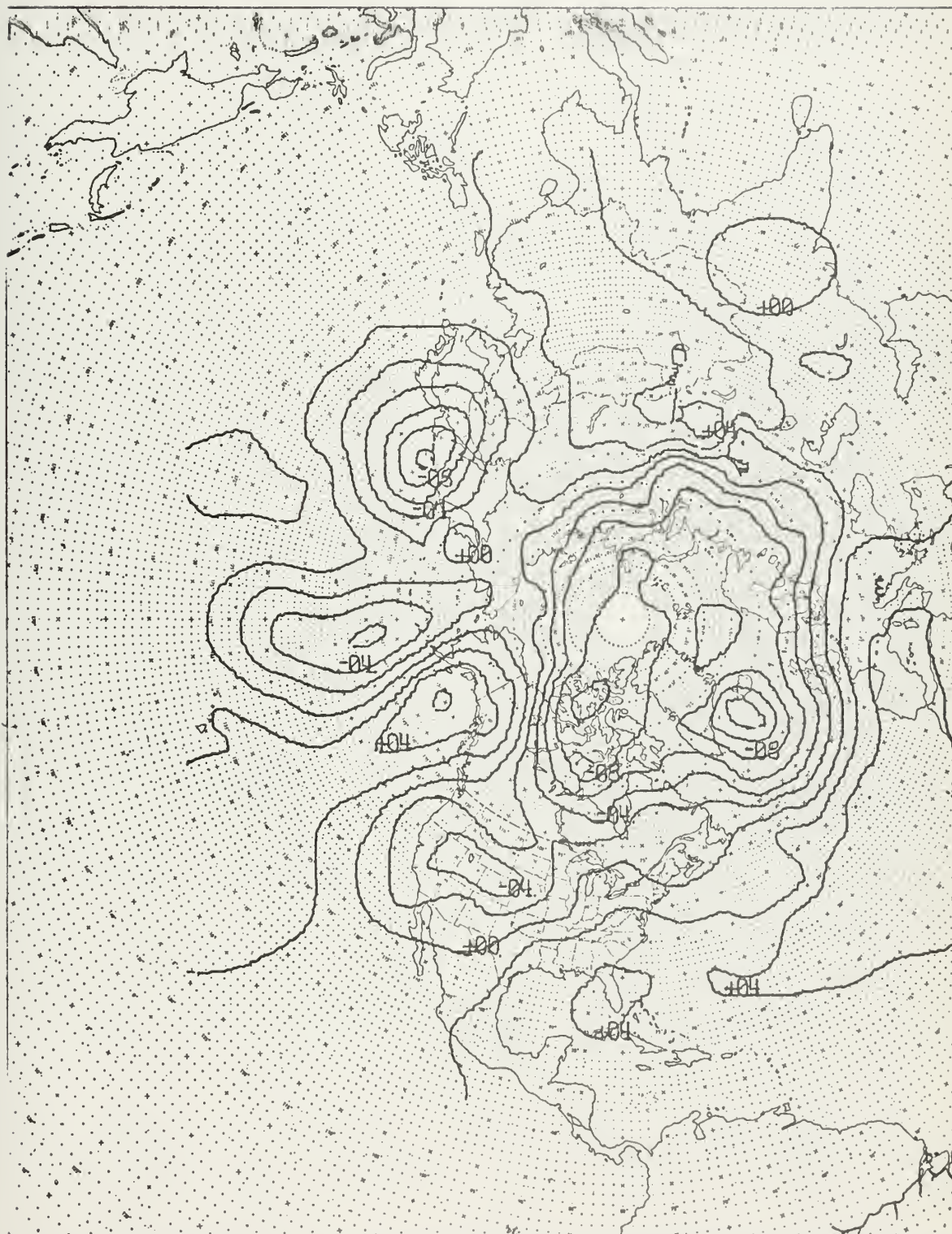
00Z 21 JAN 62 T 1000



SCALE: 1:120,000,000

FLEET NUMERICAL WEATHER FACILITY, MONTEREY, CALIFORNIA

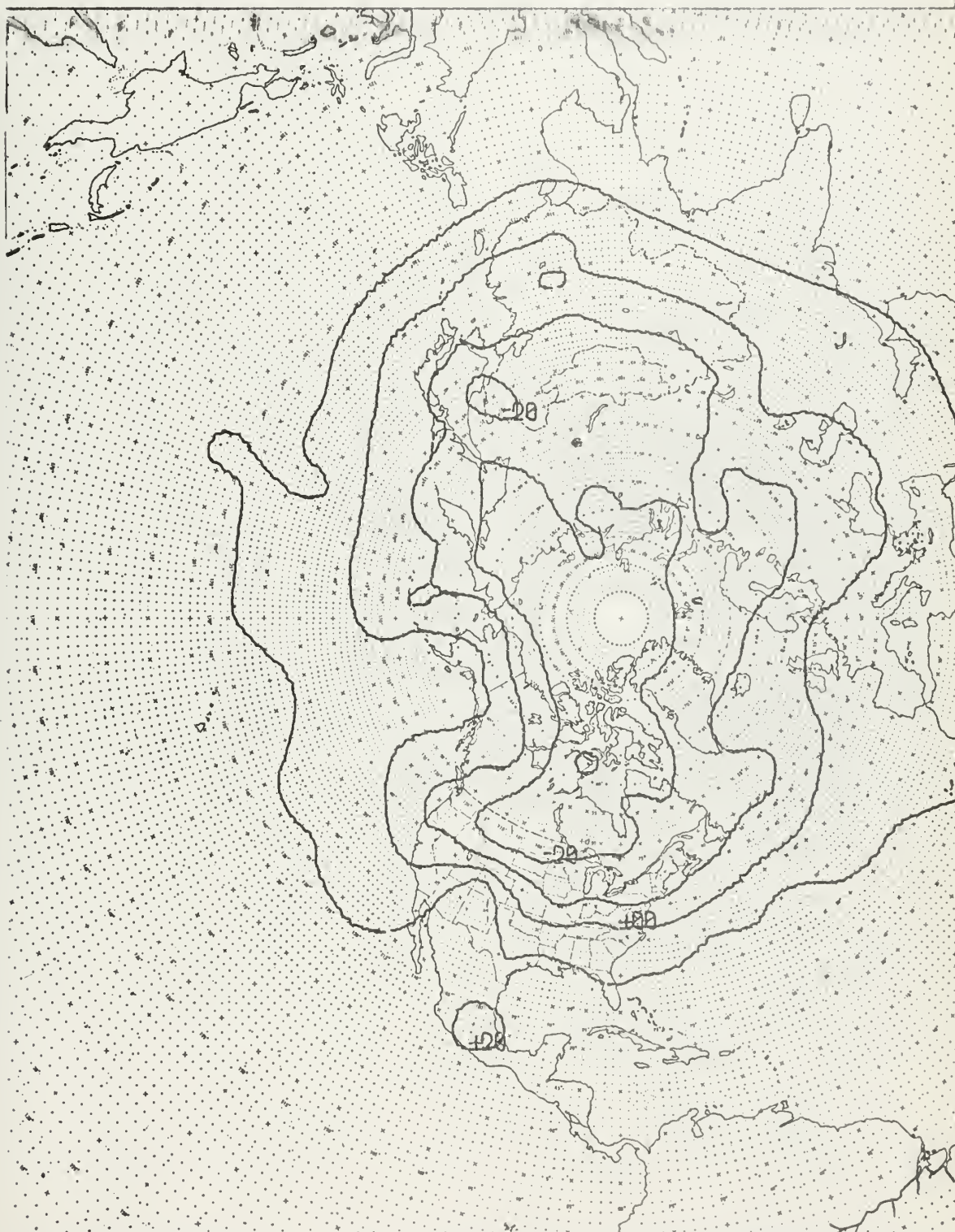
00Z 21 JAN 62 D 850



SCALE: 1:120,000,000

FLEET NUMERICAL WEATHER FACILITY, MONTEREY, CALIFORNIA

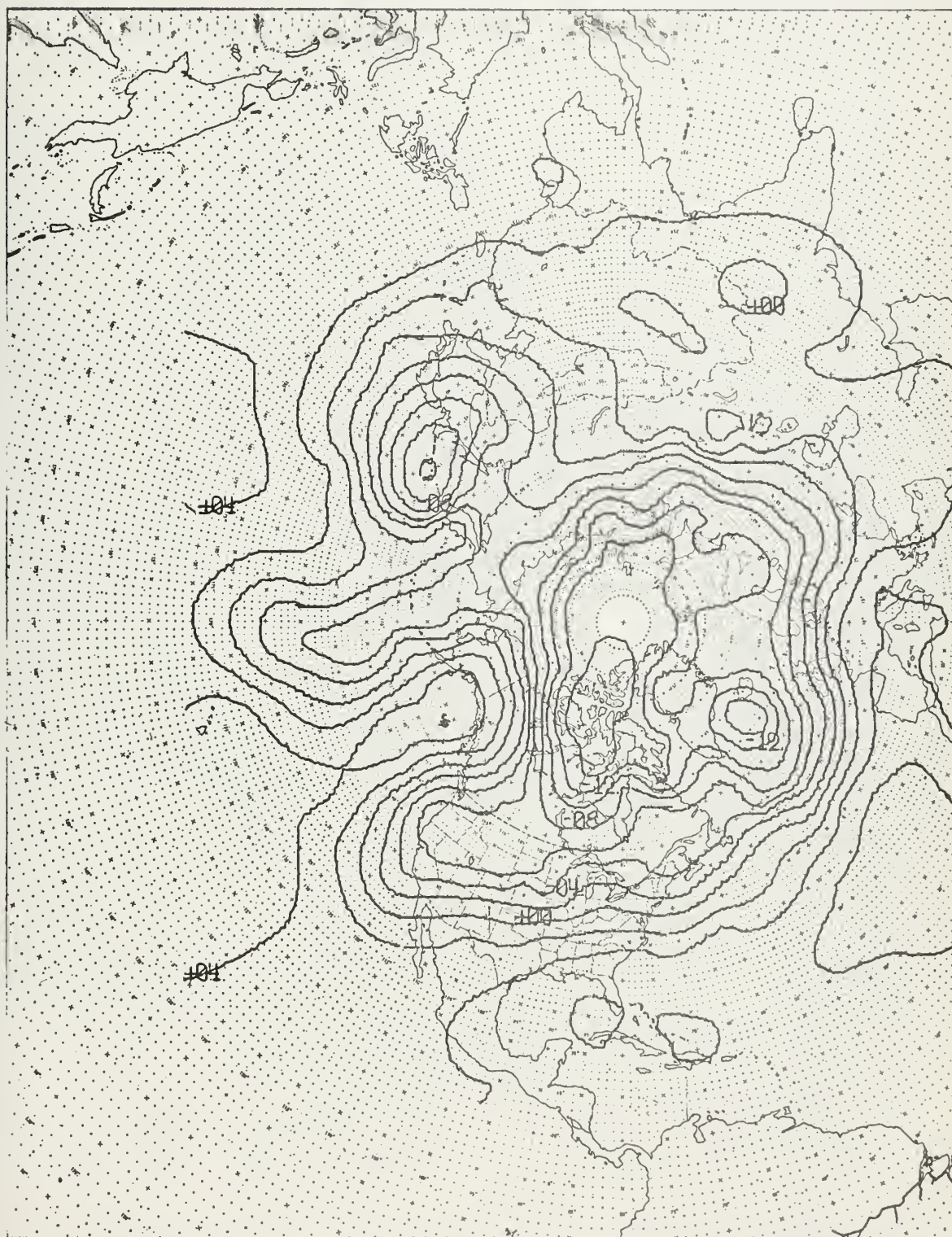
00Z 21 JAN 62 T 850



SCALE: 1:120,000,000

FLEET NUMERICAL WEATHER FACILITY, MONTEREY, CALIFORNIA

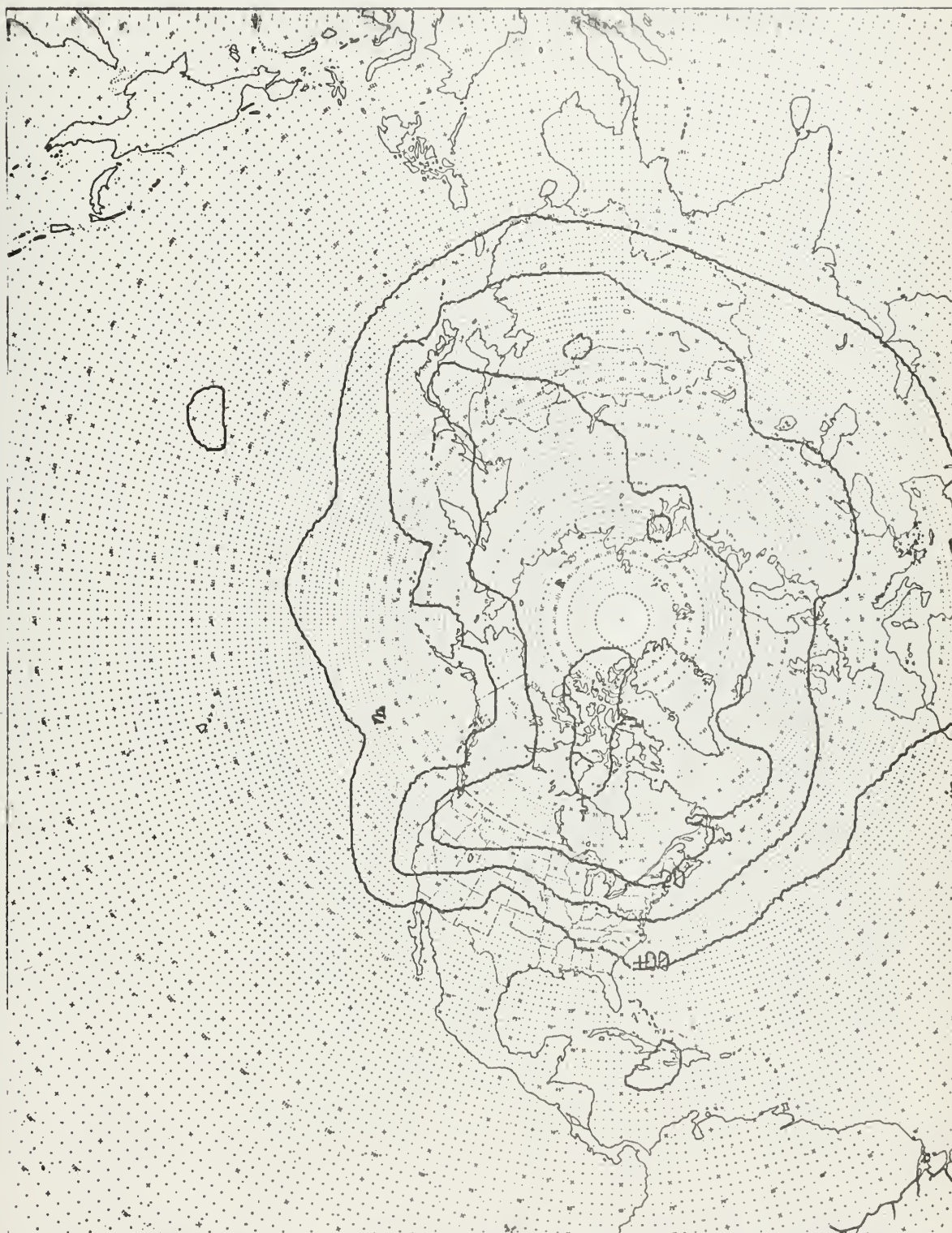
00Z 21 JAN 62 D 700



SCALE: 1:120,000,000

FLEET NUMERICAL WEATHER FACILITY, MONTEREY, CALIFORNIA

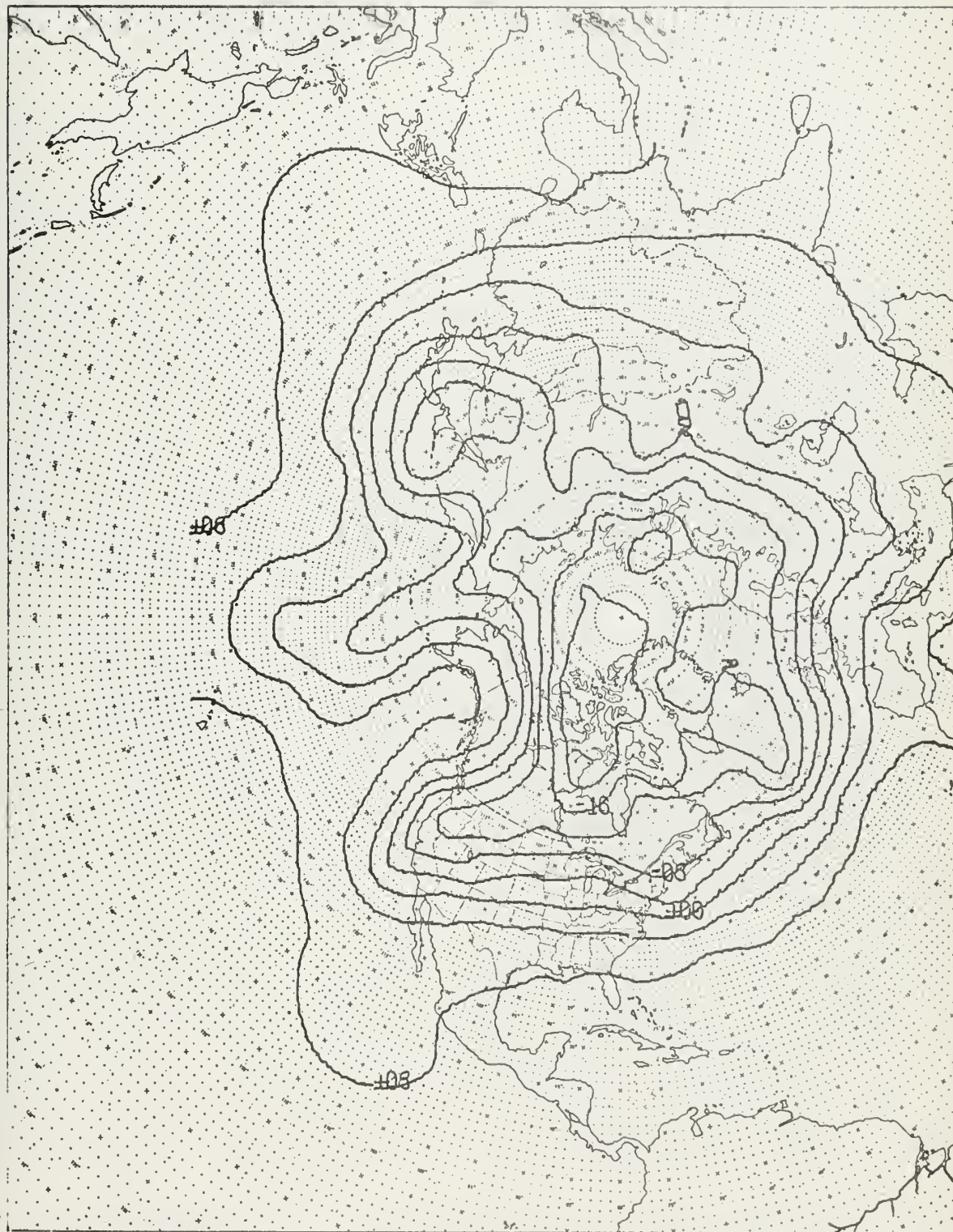
00Z 21 JAN 62 T 700



SCALE: 1:120,000,000

FLEET NUMERICAL WEATHER FACILITY, MONTEREY, CALIFORNIA

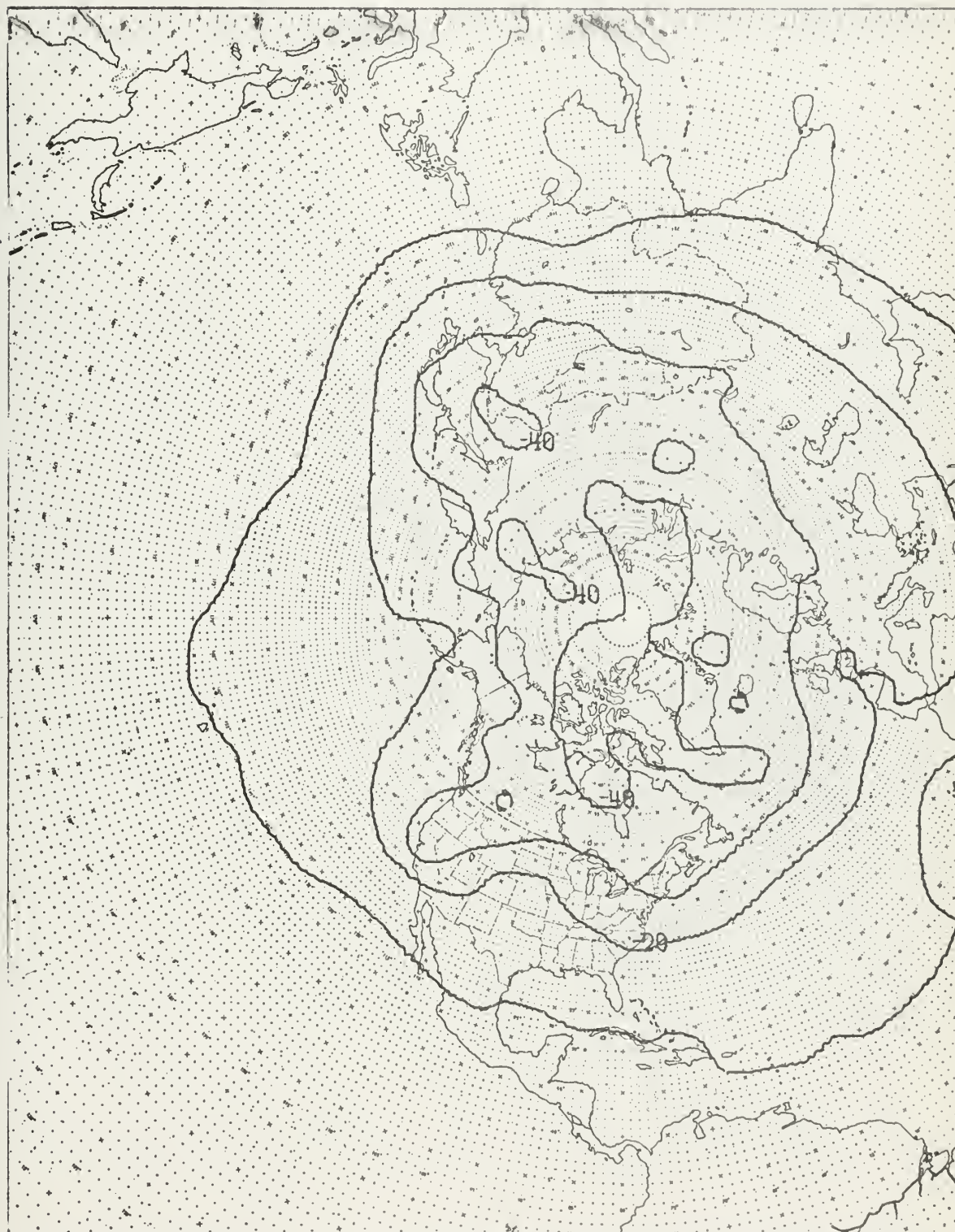
00Z 21 JAN 62 D 500



SCALE: 1:120,000,000

FLEET NUMERICAL WEATHER FACILITY, MONTEREY, CALIFORNIA

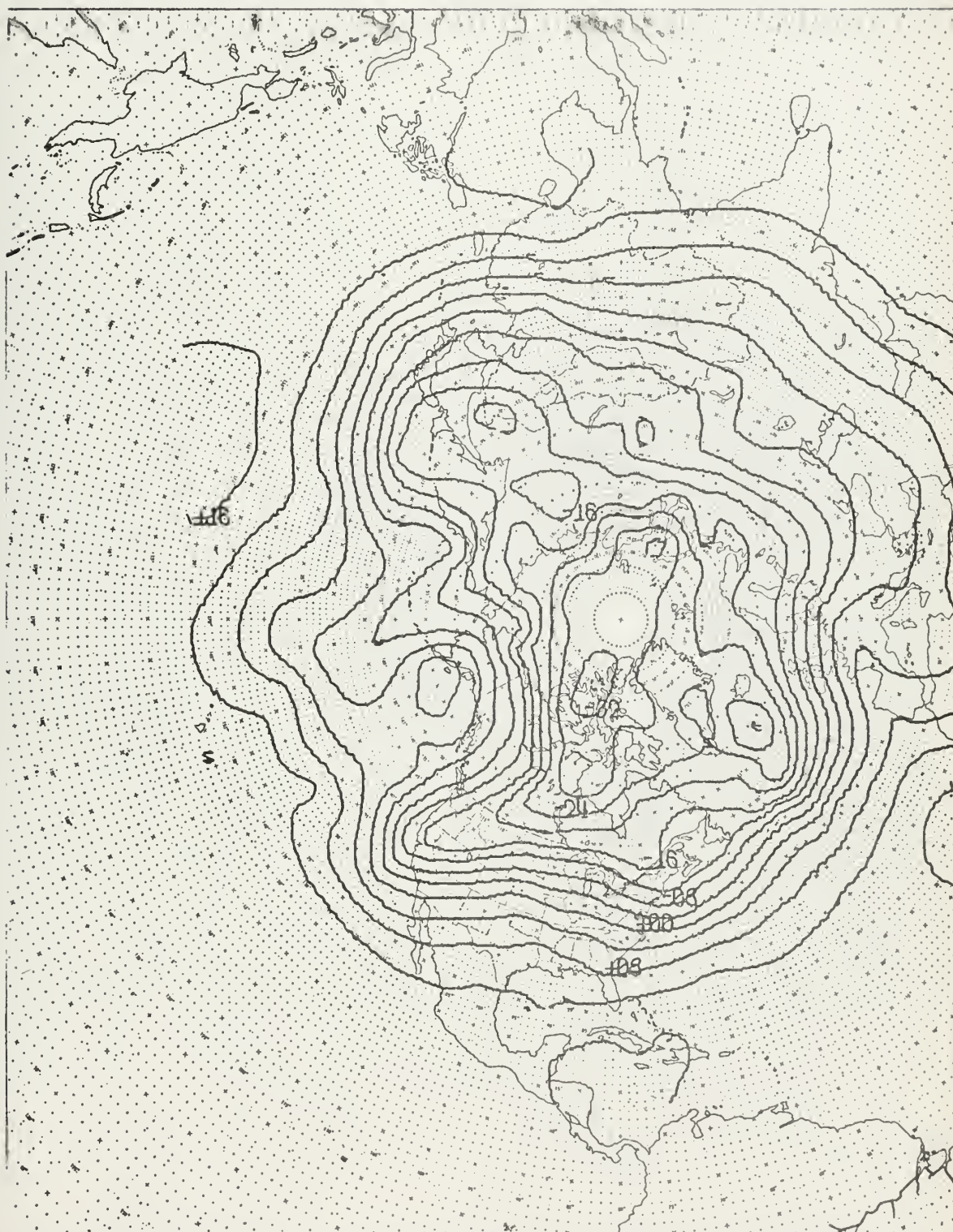
00Z 21 JAN 62 T 500



SCALE: 1:120,000,000

FLEET NUMERICAL WEATHER FACILITY, MONTEREY, CALIFORNIA

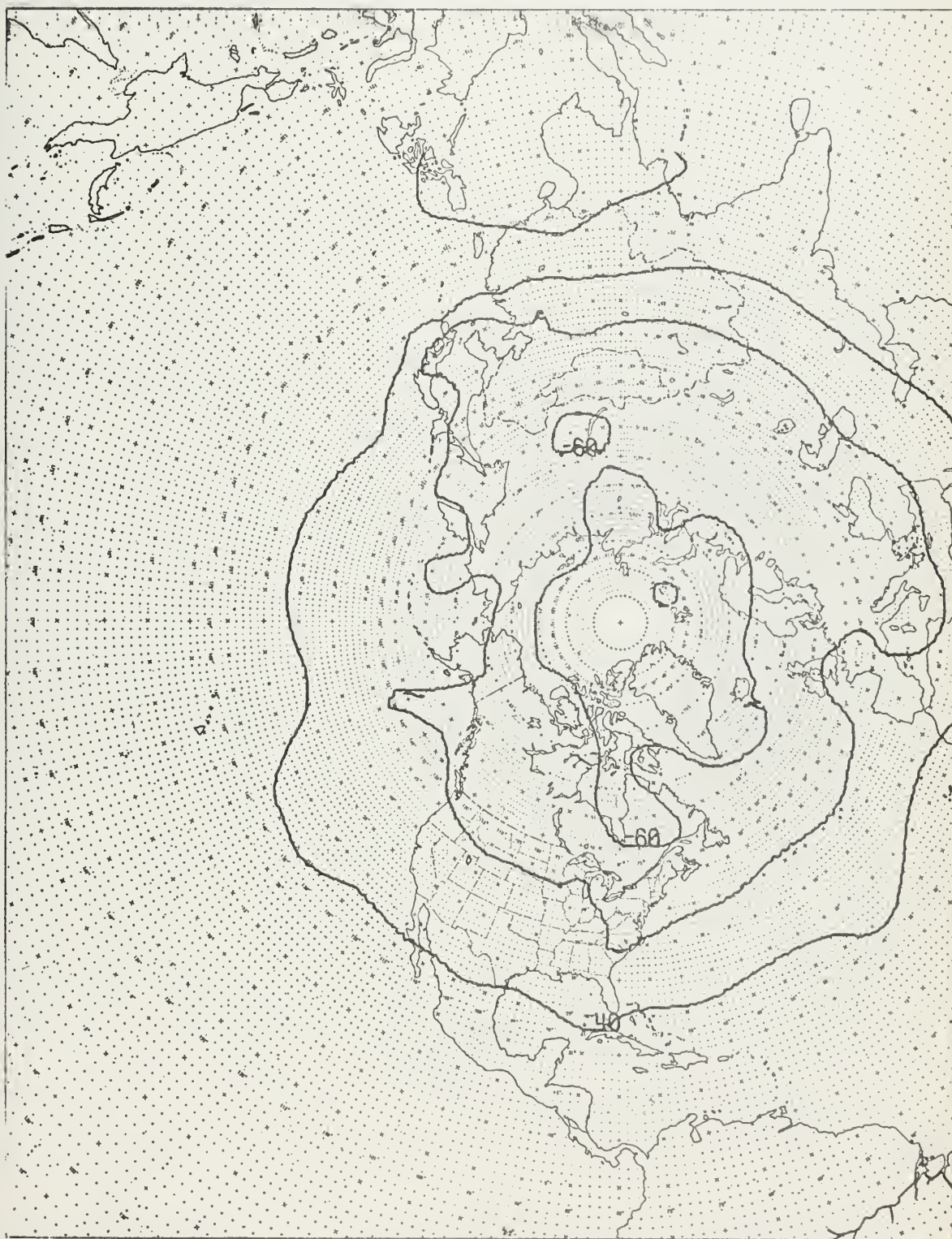
00Z 21 JAN 62 D 300



SCALE: 1:120,000,000

FLEET NUMERICAL WEATHER FACILITY, MONTEREY, CALIFORNIA

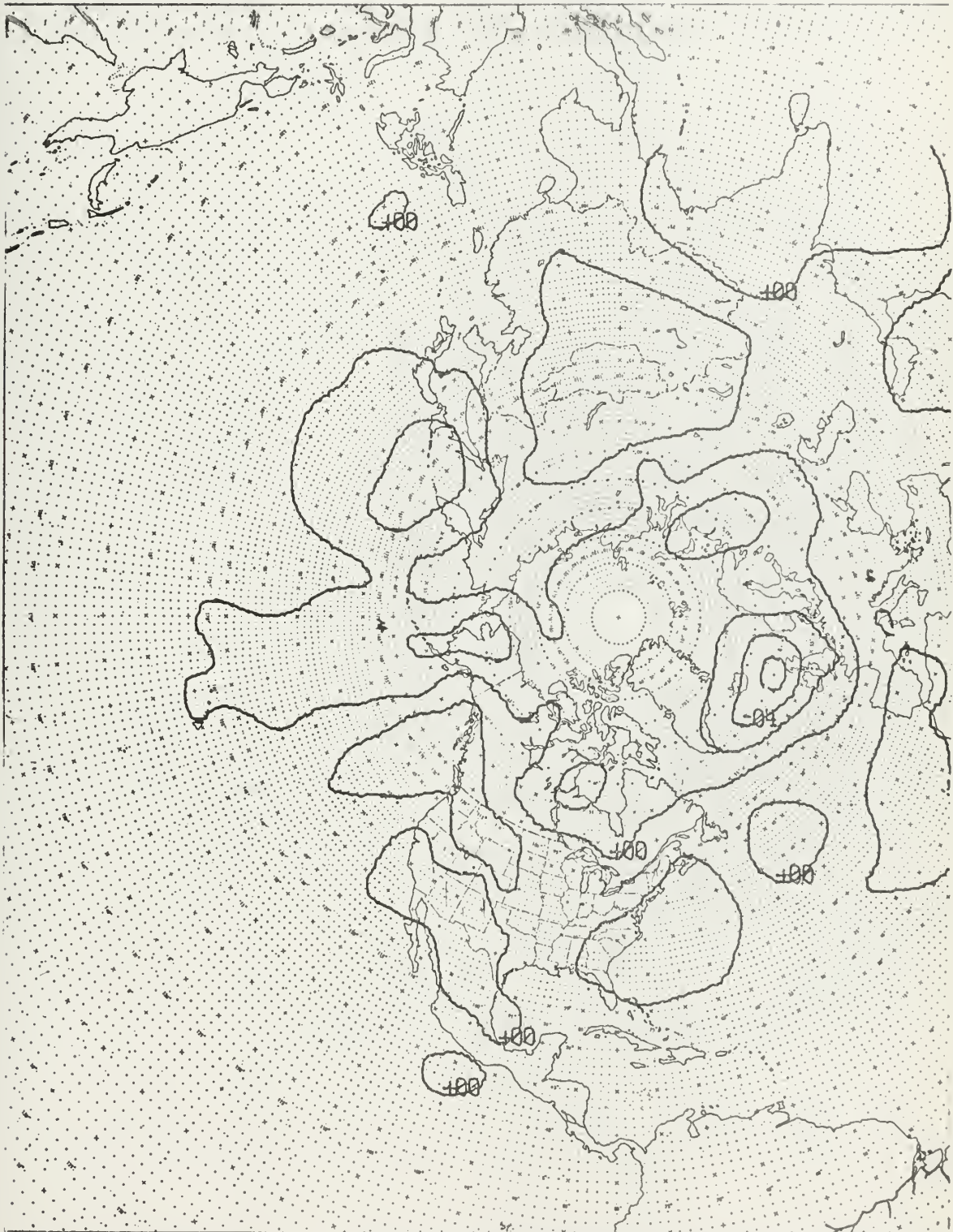
00Z 21 JAN 62 T 300



SCALE: 1:120,000,000

FLEET NUMERICAL WEATHER FACILITY, MONTEREY, CALIFORNIA

00Z 22 JAN 62 D 1000



SCALE: 1:120,000,000

FLEET NUMERICAL WEATHER FACILITY, MONTEREY, CALIFORNIA

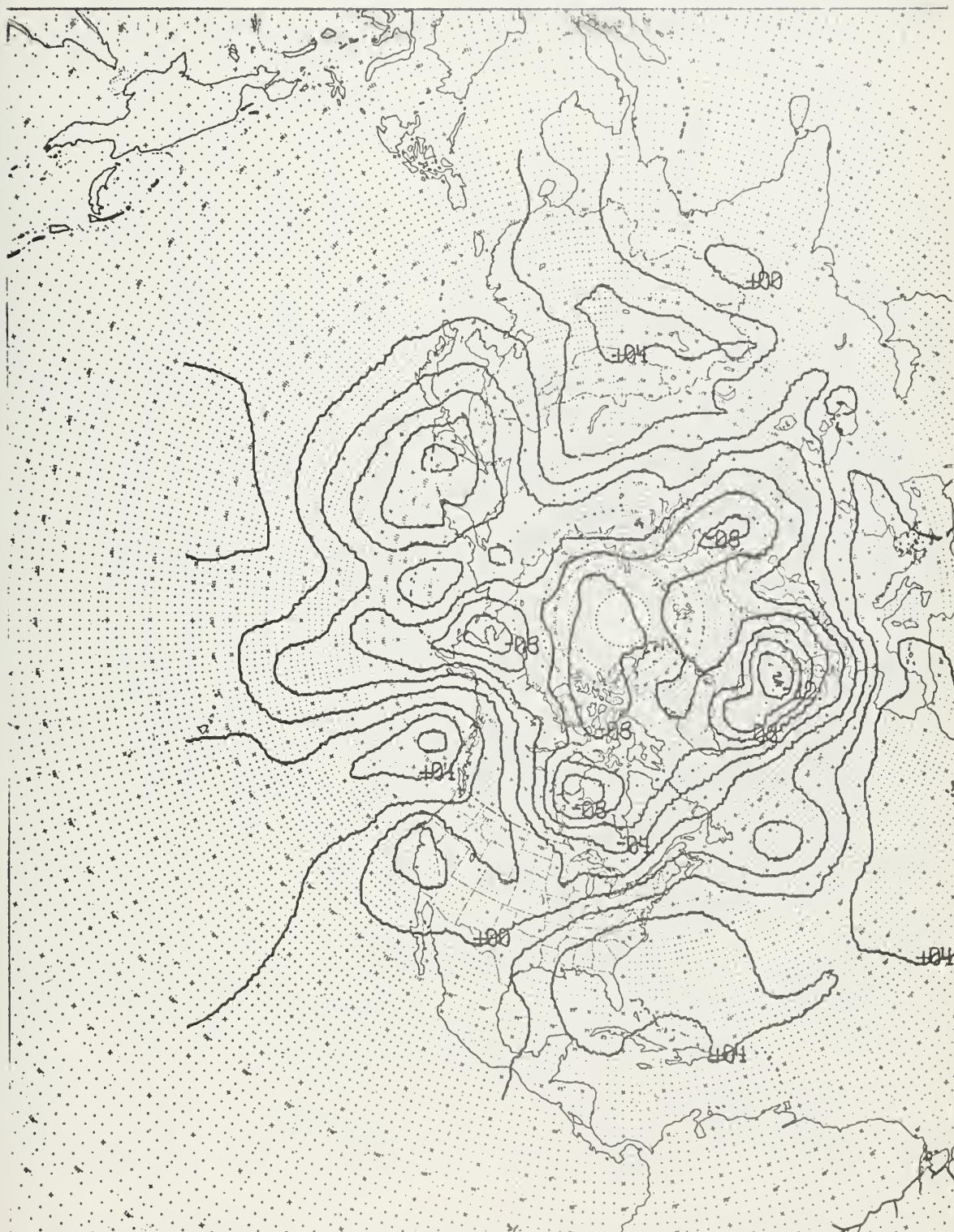
00Z 22 JAN 62 T 1000



SCALE: 1:120,000,000

FLEET NUMERICAL WEATHER FACILITY, MONTEREY, CALIFORNIA

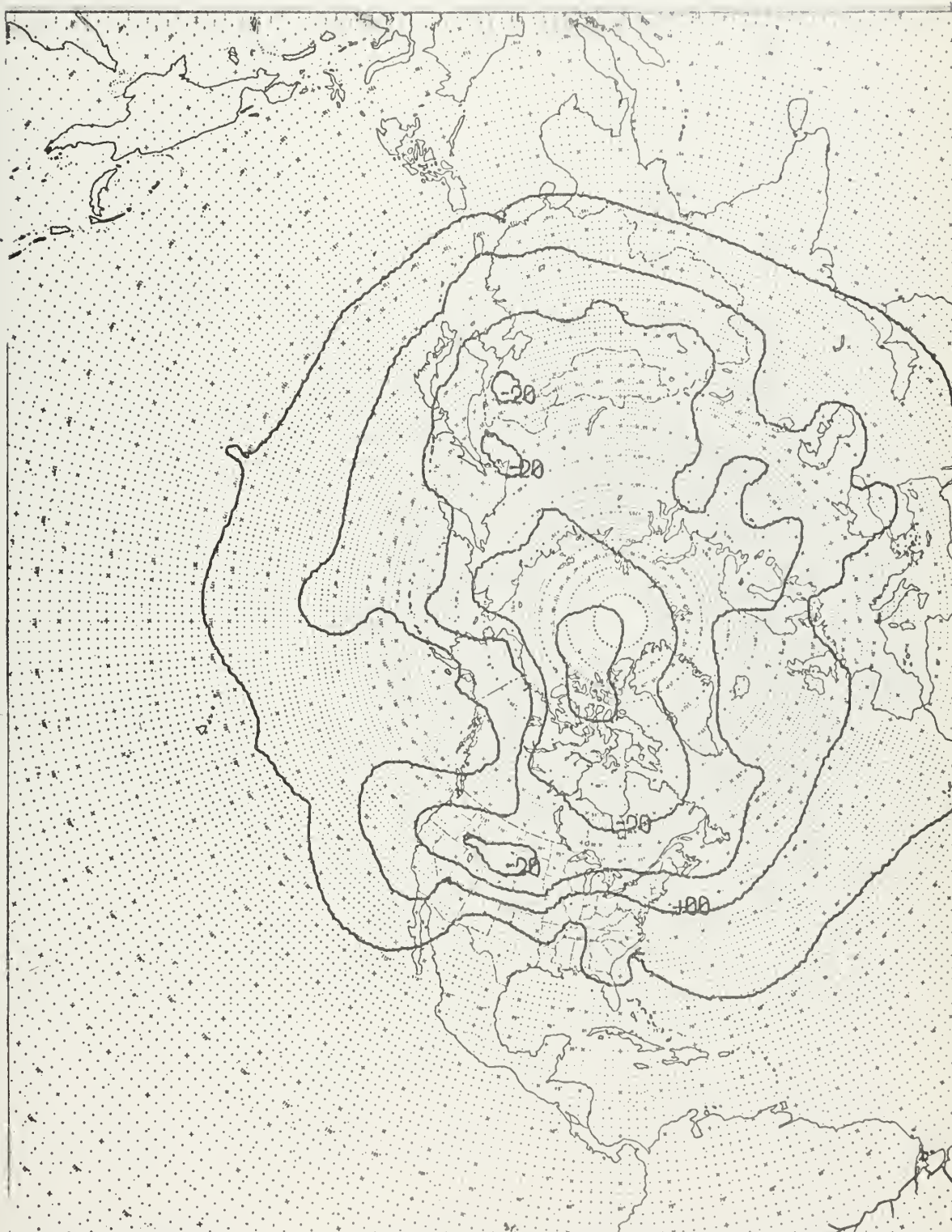
00Z 22 JAN 62 D 850



SCALE: 1:120,000,000

FLEET NUMERICAL WEATHER FACILITY, MONTEREY, CALIFORNIA

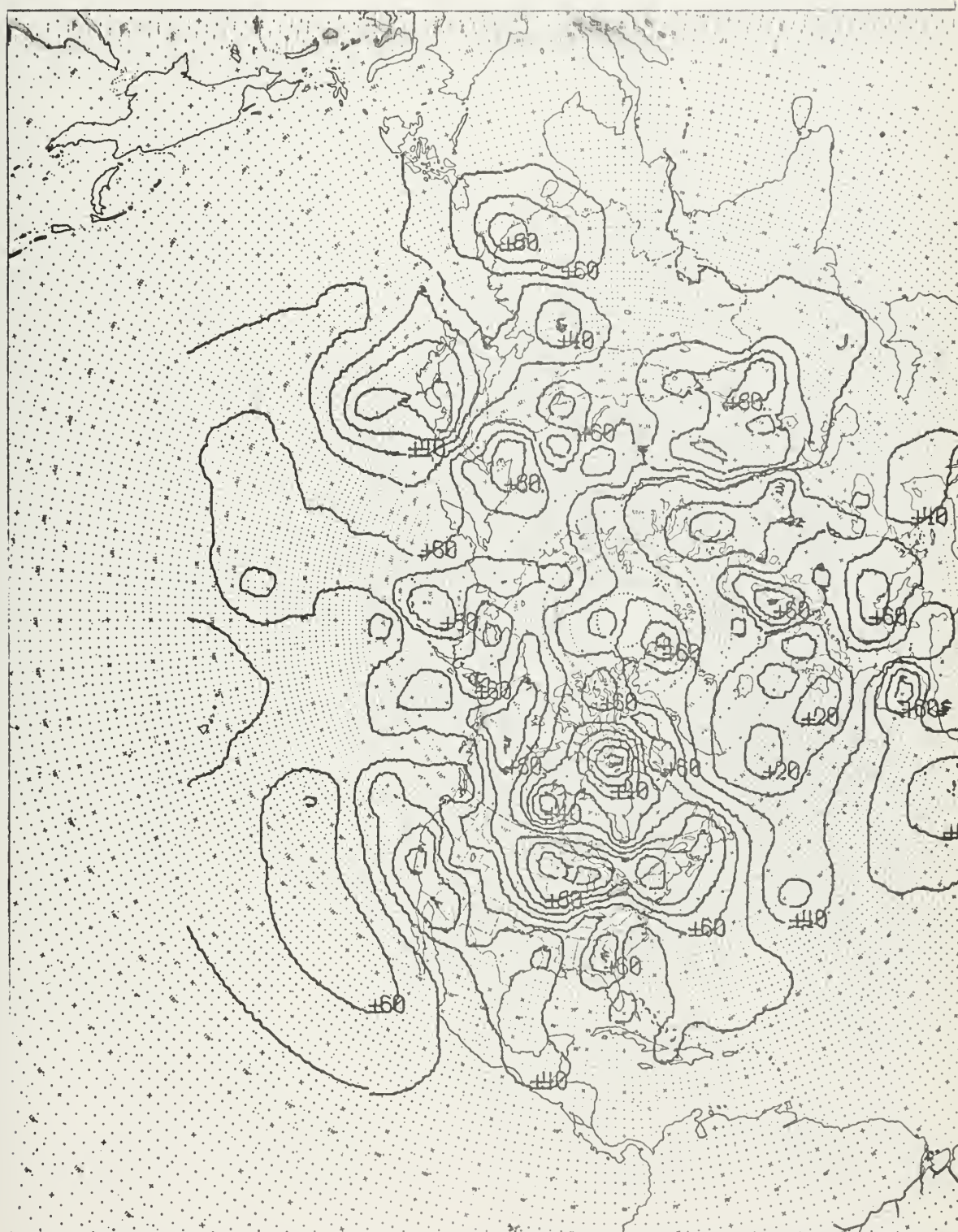
00Z 22 JAN 62 T 850



SCALE: 1:120,000,000

FLEET NUMERICAL WEATHER FACILITY, MONTEREY, CALIFORNIA

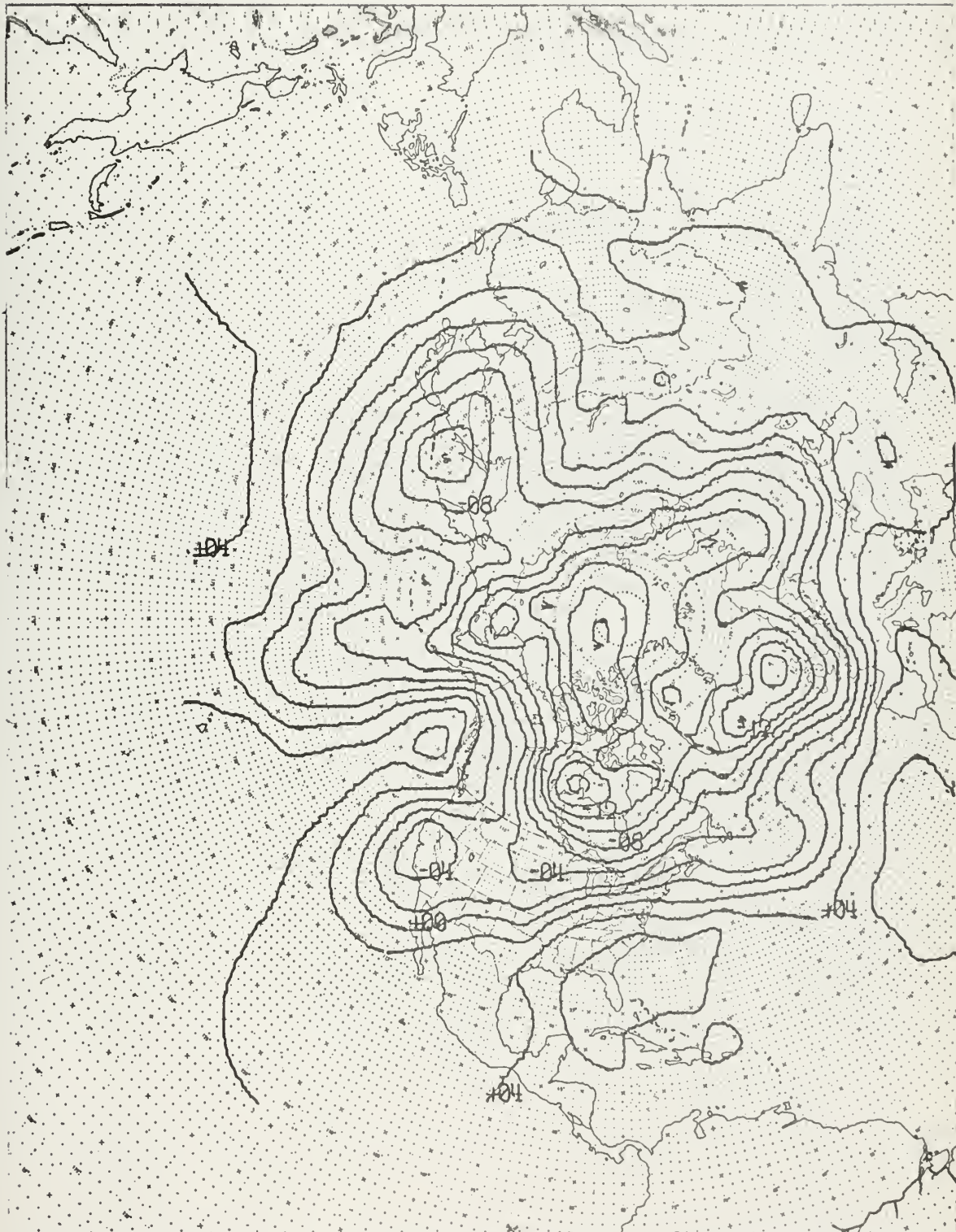
00Z 22 JAN 62 SIG 850



SCALE: 1:120,000,000

FLEET NUMERICAL WEATHER FACILITY, MONTEREY, CALIFORNIA

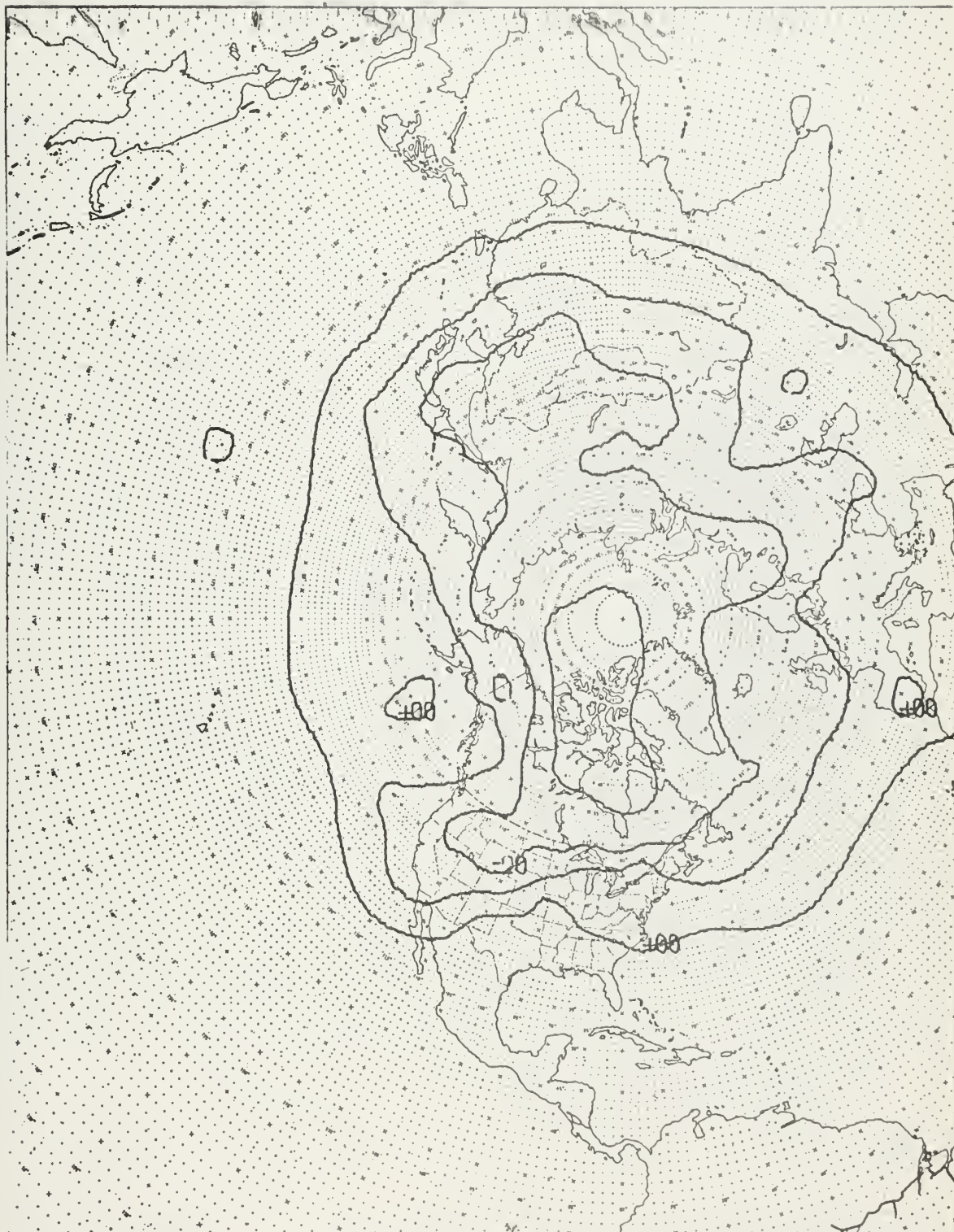
00Z 22 JAN 62 D 700



SCALE: 1:120,000,000

FLEET NUMERICAL WEATHER FACILITY, MONTEREY, CALIFORNIA

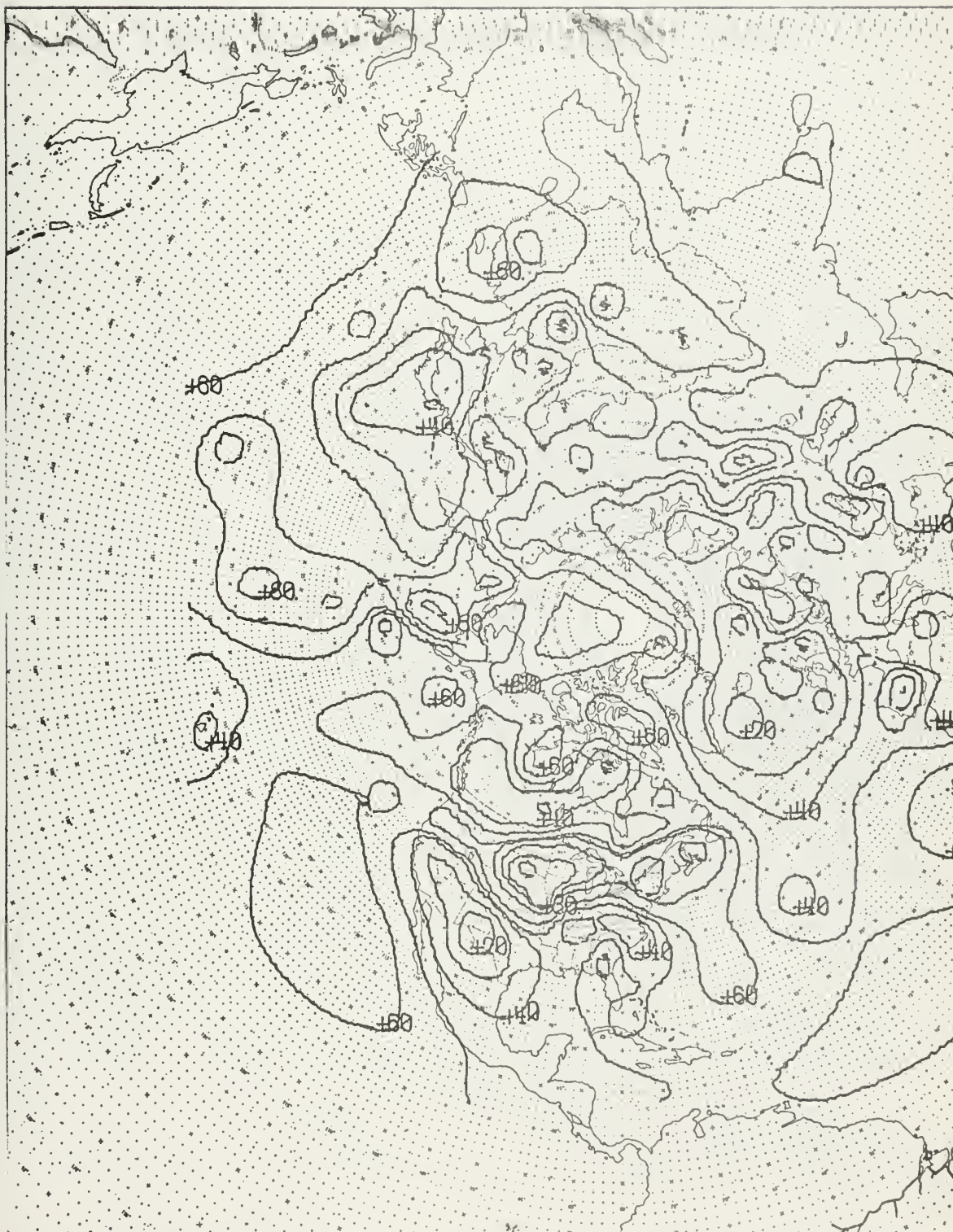
00Z 22 JAN 62 T 700



SCALE: 1:120,000,000

FLEET NUMERICAL WEATHER FACILITY, MONTEREY, CALIFORNIA

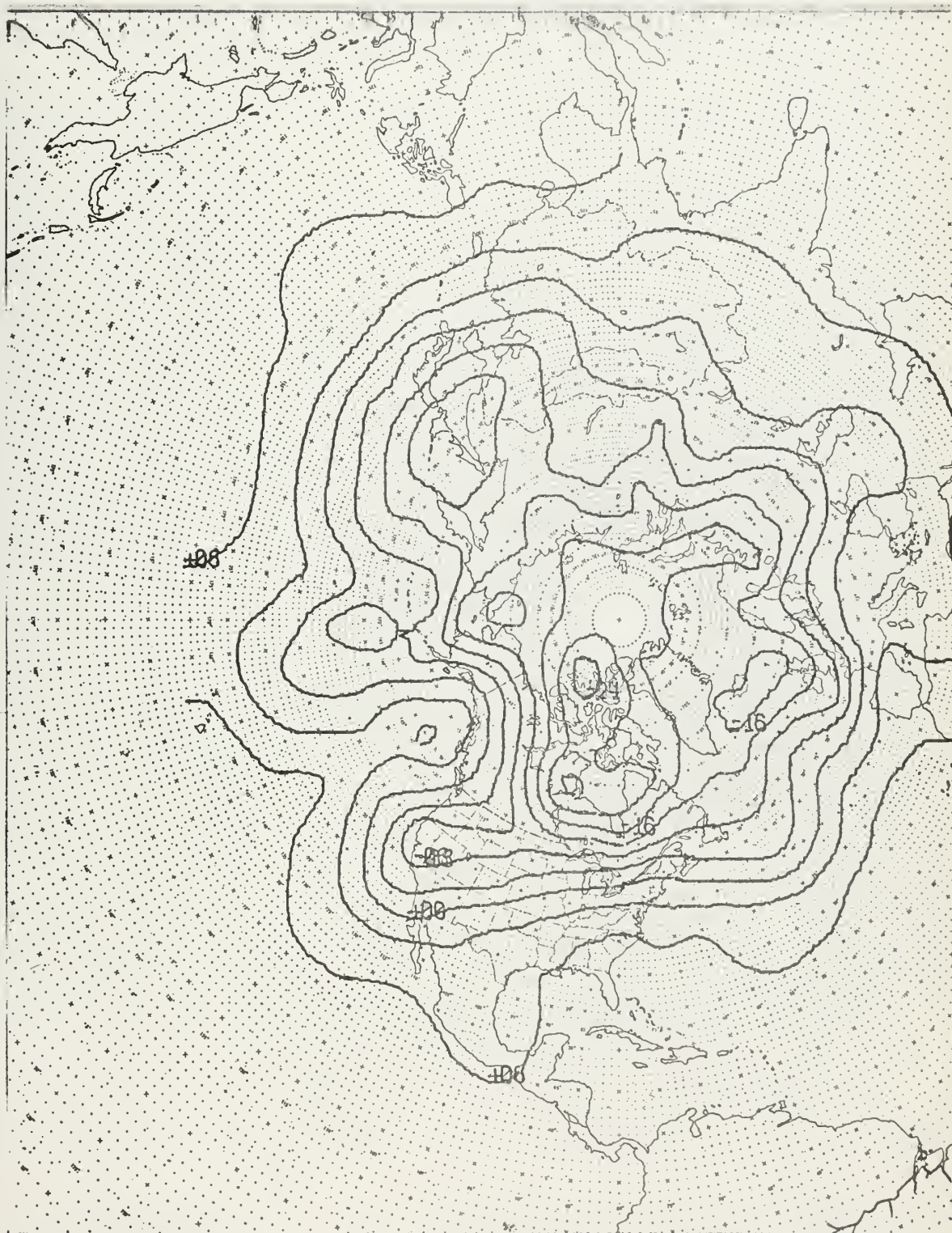
00Z 22 JAN 62 SIG 700



SCALE: 1:120,000,000

FLEET NUMERICAL WEATHER FACILITY, MONTEREY, CALIFORNIA

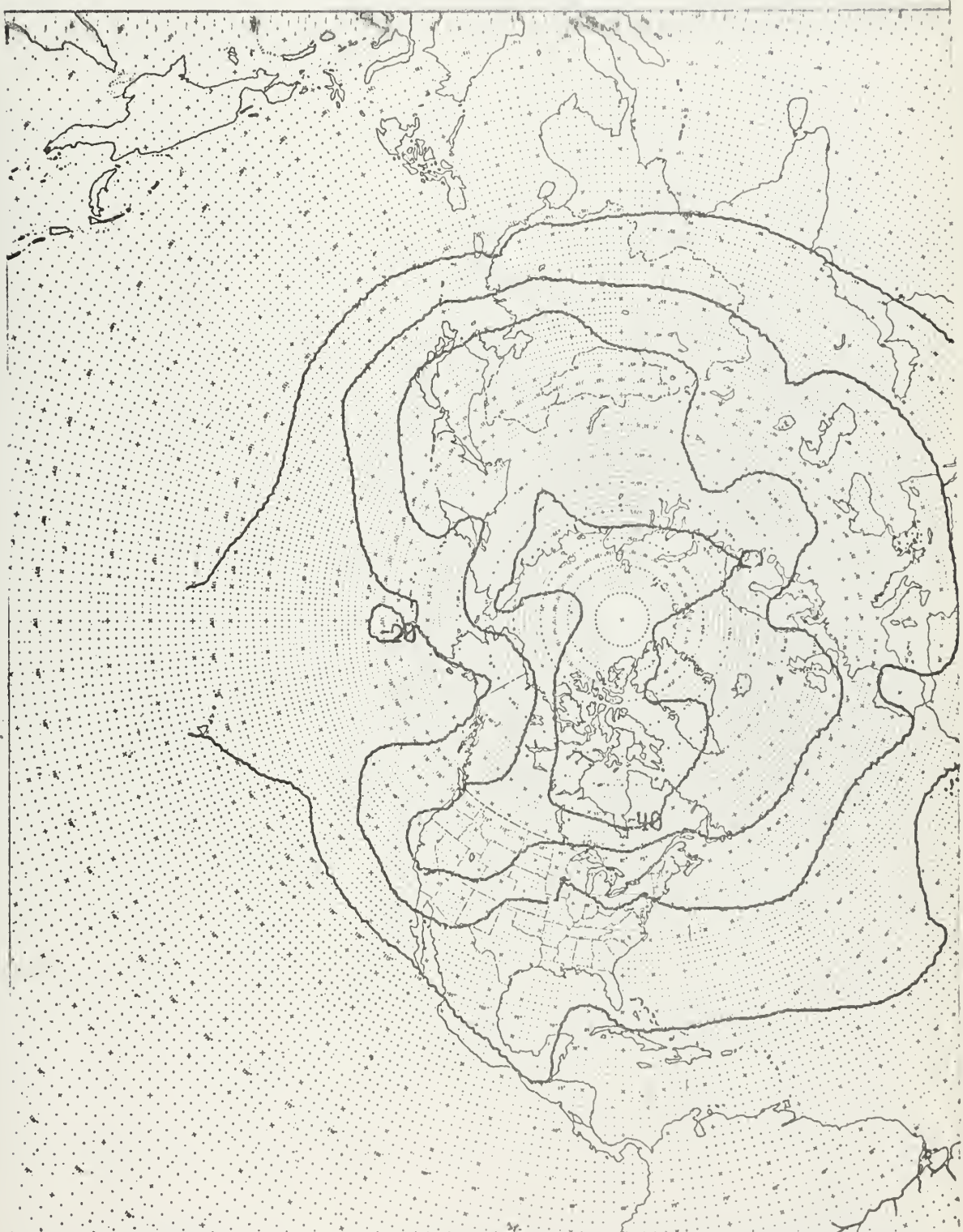
00Z 22 JAN 62 D 500



SCALE: 1:120,000,000

FLEET NUMERICAL WEATHER FACILITY, MONTEREY, CALIFORNIA

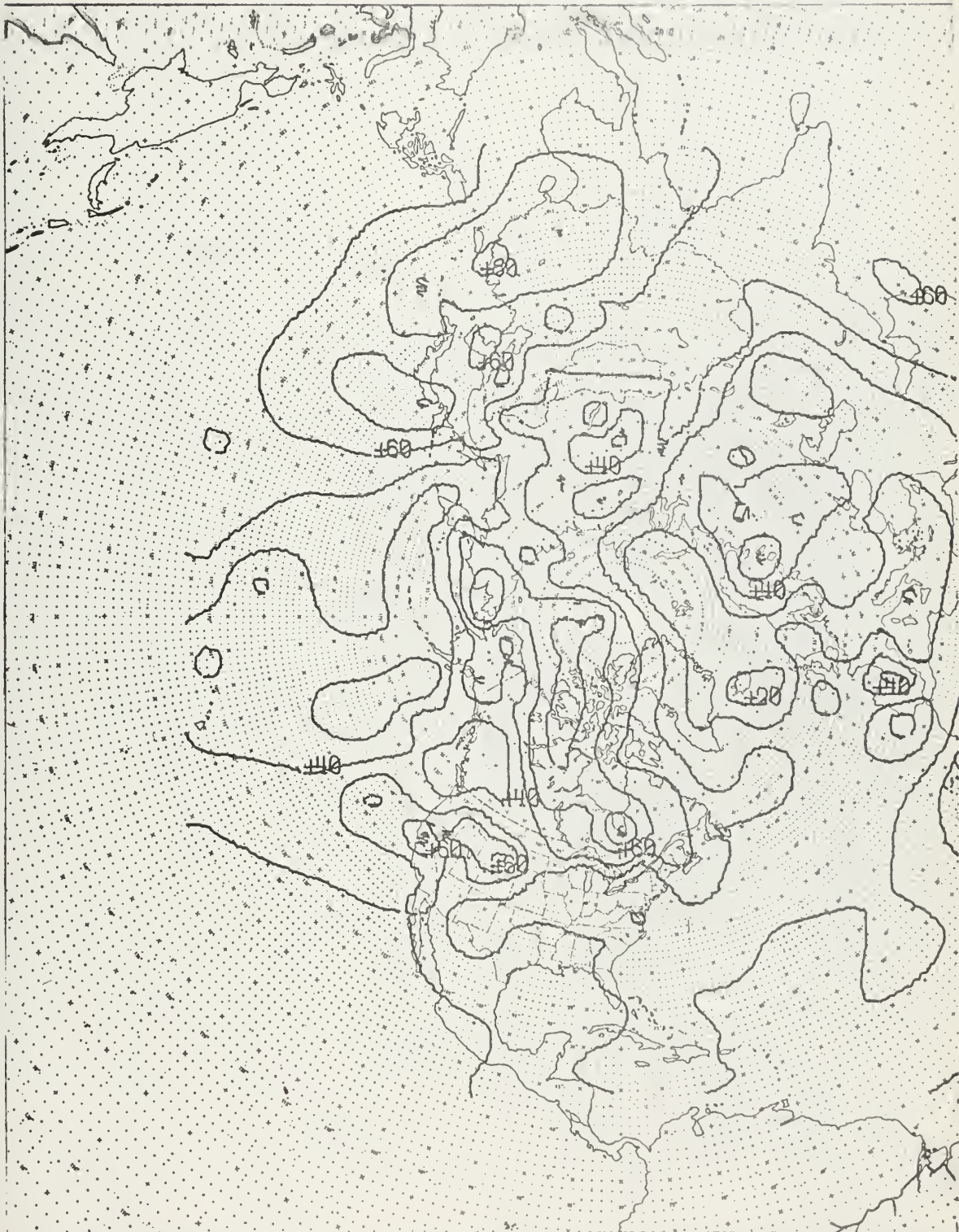
00Z 22 JAN 62 T 500



SCALE: 1:120,000,000

FLEET NUMERICAL WEATHER FACILITY, MONTEREY, CALIFORNIA

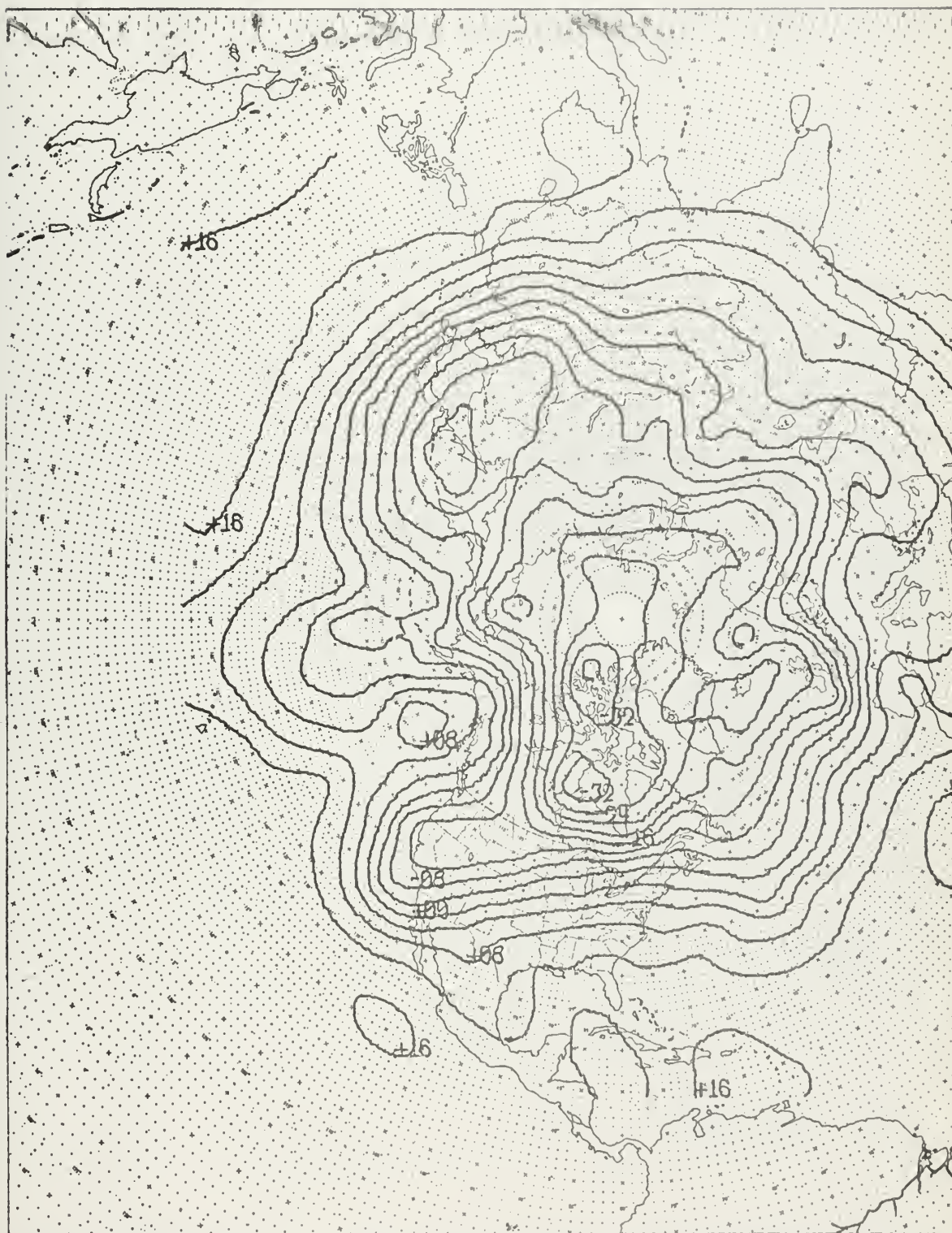
00Z 22 JAN 62 SIG 500



SCALE: 1:120,000,000

FLEET NUMERICAL WEATHER FACILITY, MONTEREY, CALIFORNIA

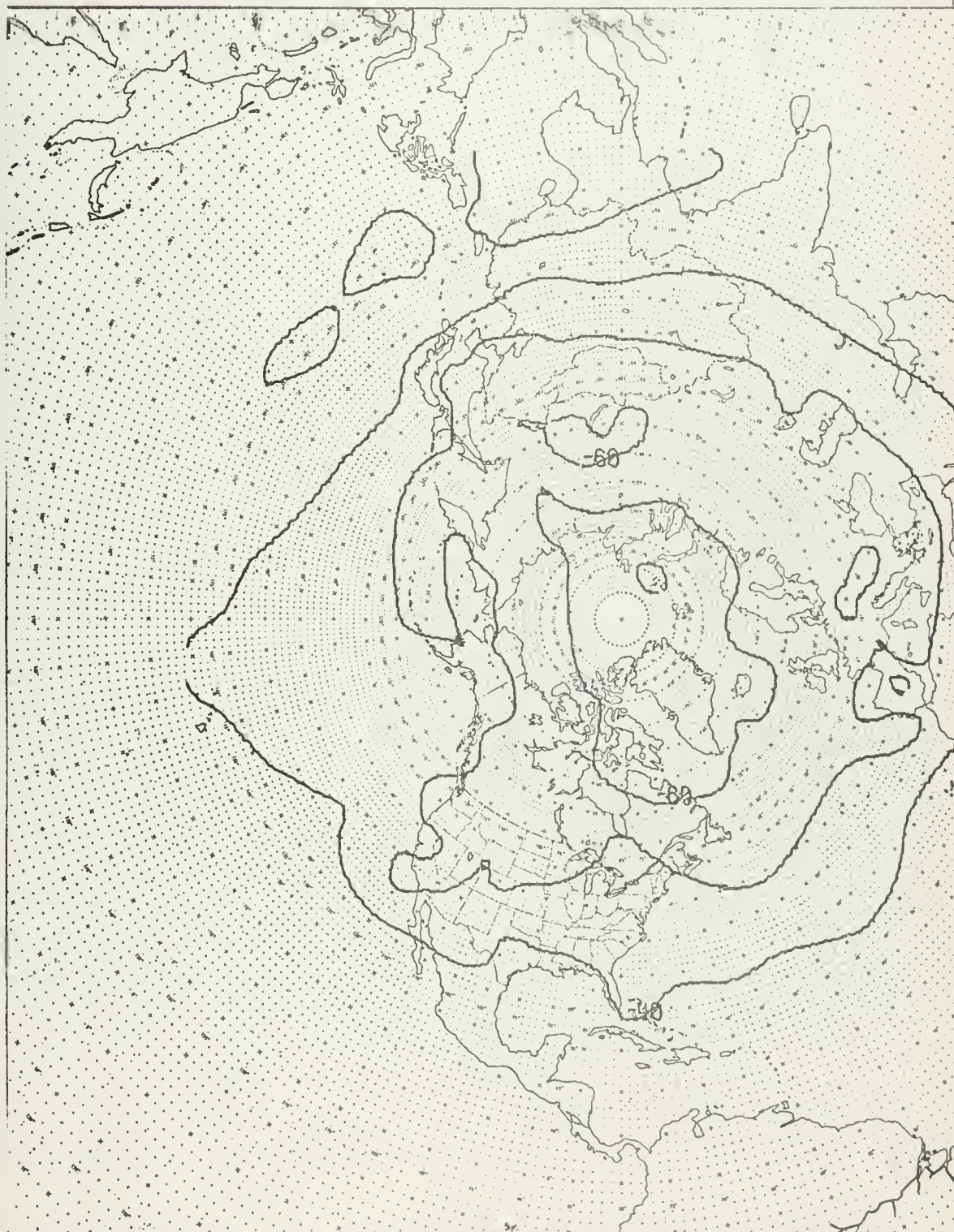
00Z 22 JAN 62 D 300



SCALE: 1:120,000,000

FLEET NUMERICAL WEATHER FACILITY, MONTEREY, CALIFORNIA

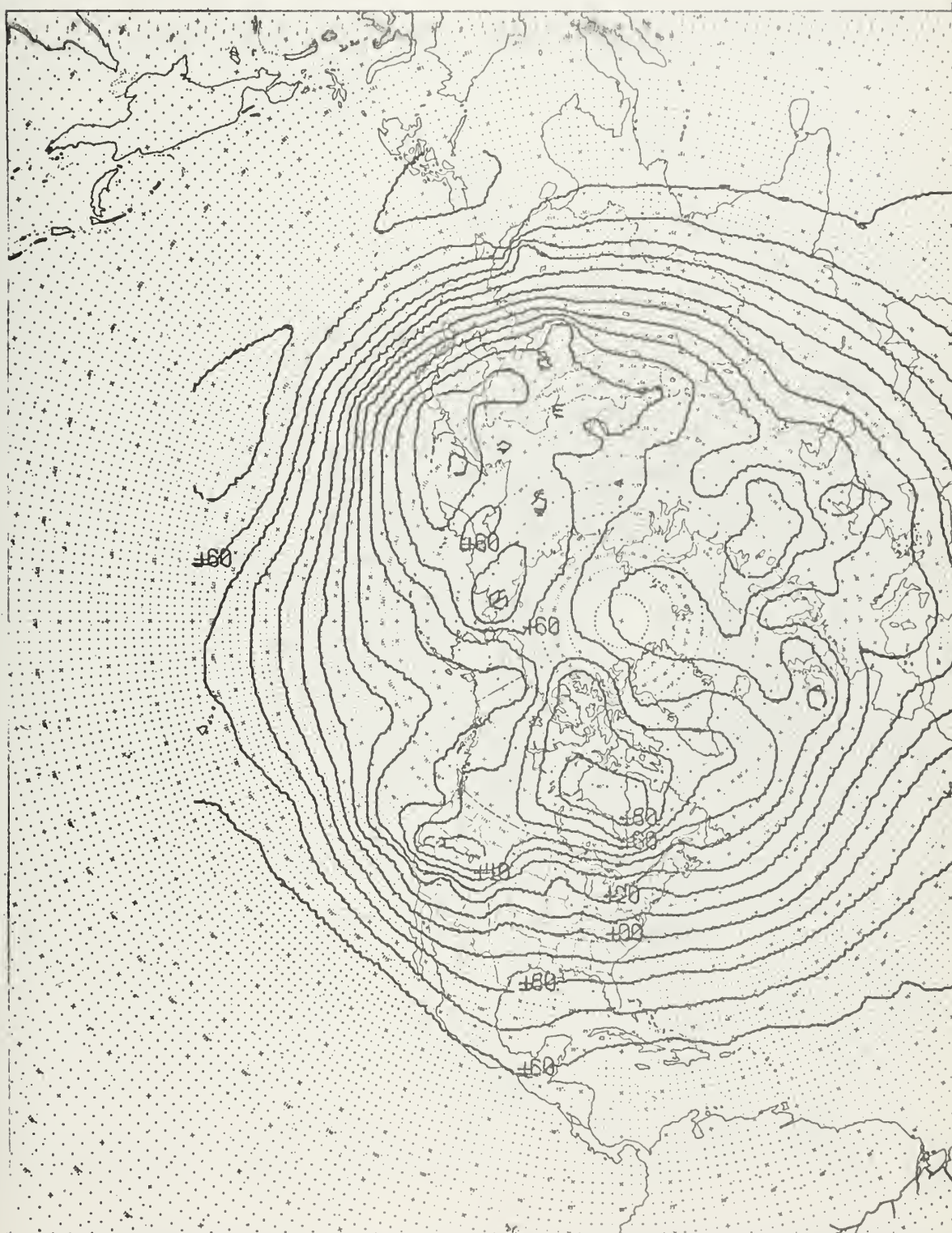
00Z 22 JAN 62 T 300



SCALE: 1:120,000,000

FLEET NUMERICAL WEATHER FACILITY, MONTEREY, CALIFORNIA

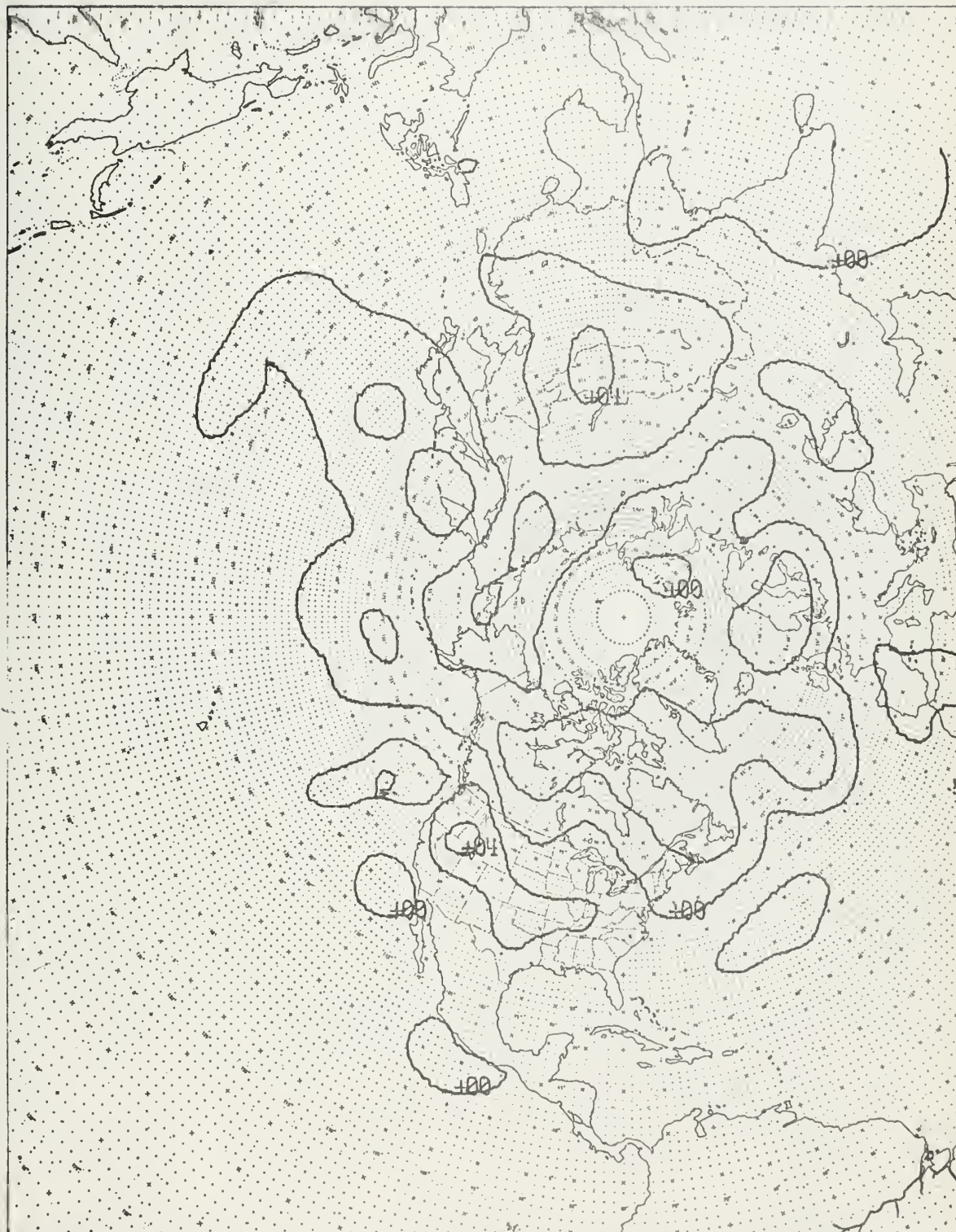
00Z 22 JAN 62 SIG 300



SCALE: 1:120,000,000

FLEET NUMERICAL WEATHER FACILITY, MONTEREY, CALIFORNIA

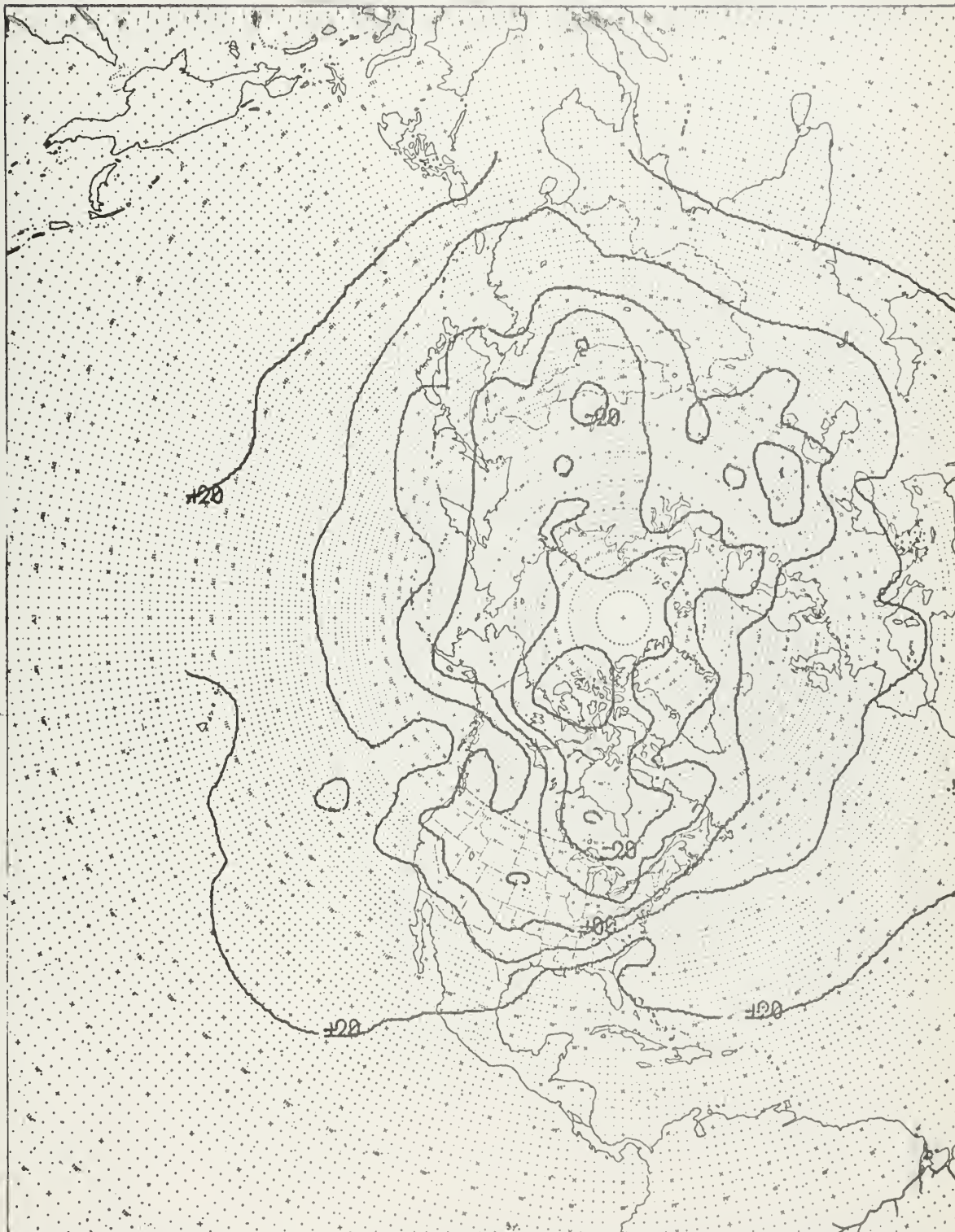
12Z 23 JAN 62 D 1000



SCALE: 1:120,000,000

FLEET NUMERICAL WEATHER FACILITY, MONTEREY, CALIFORNIA

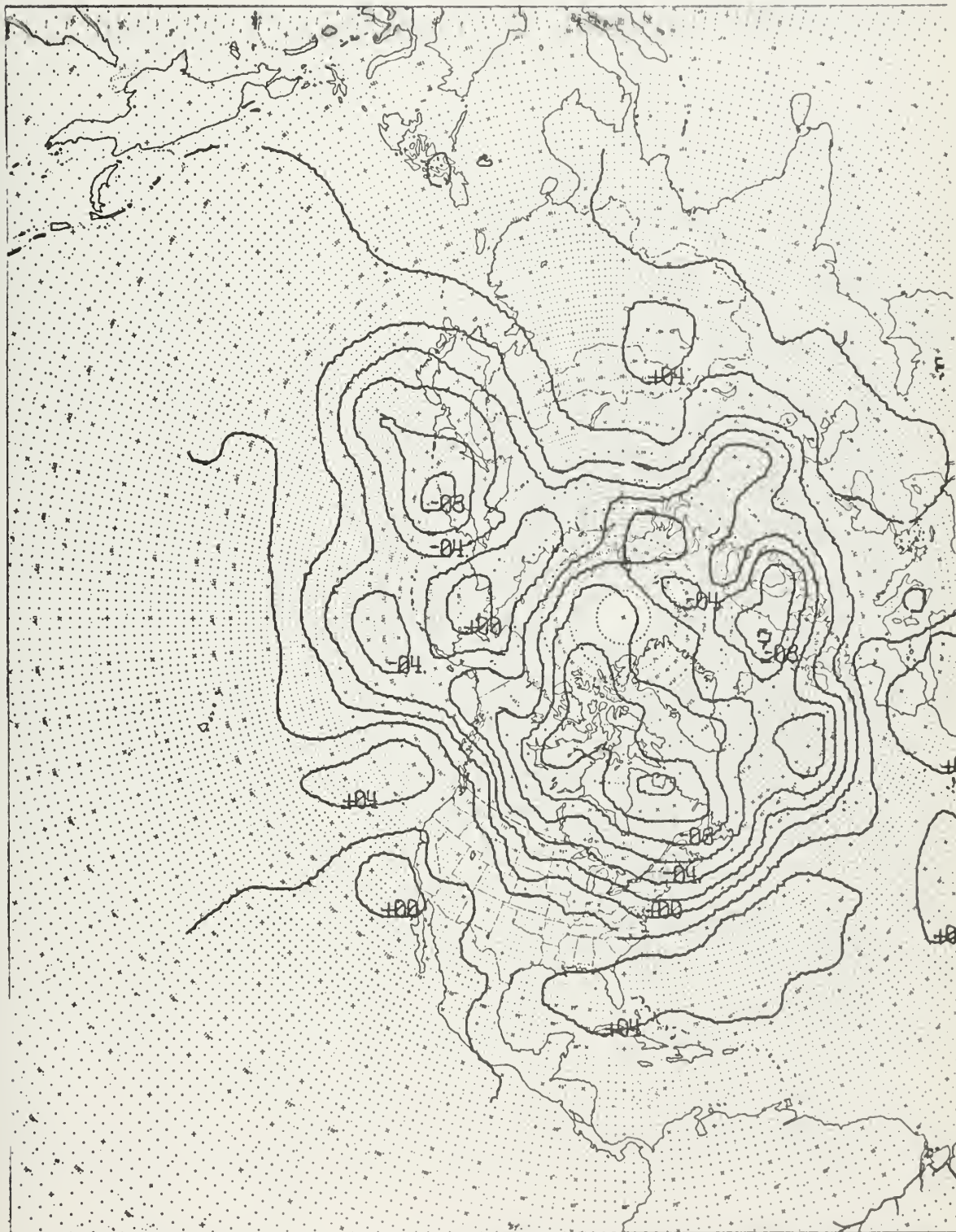
12Z 23 JAN 62 T 1000



SCALE: 1:120,000,000

FLEET NUMERICAL WEATHER FACILITY, MONTEREY, CALIFORNIA

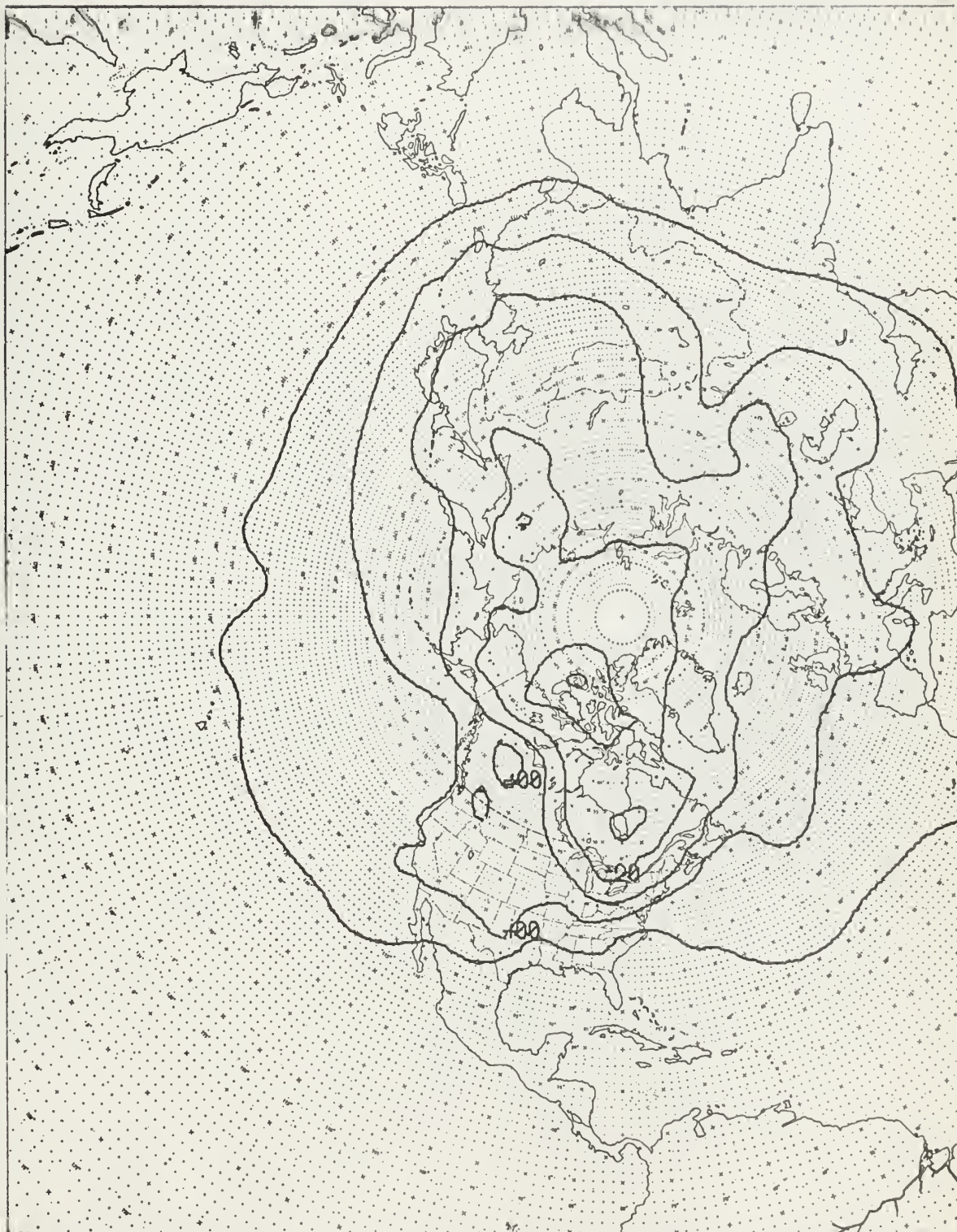
12Z 23 JAN 62 D 850



SCALE: 1:120,000,000

FLEET NUMERICAL WEATHER FACILITY, MONTEREY, CALIFORNIA

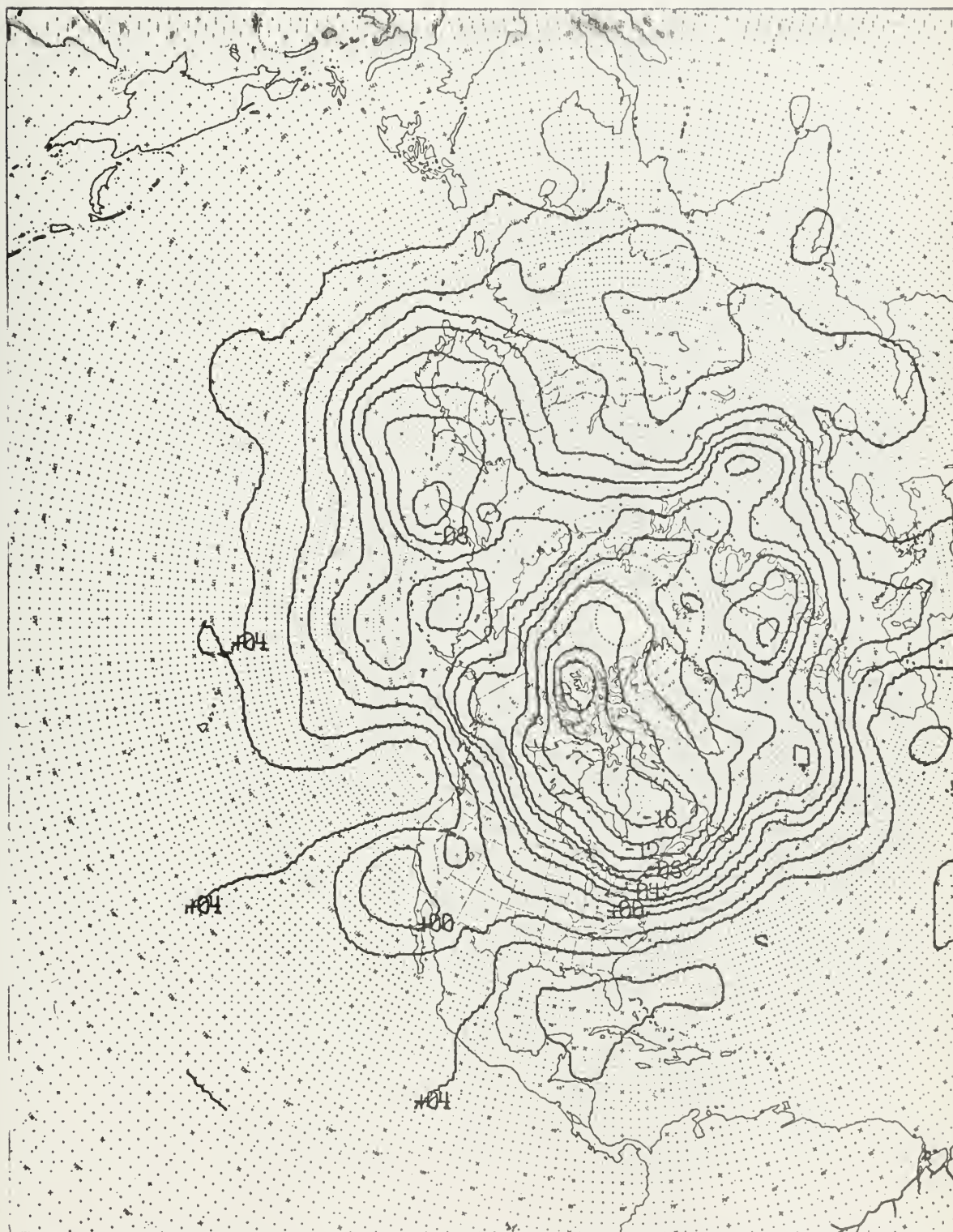
12Z 23 JAN 62 T 850



SCALE: 1:120,000,000

FLEET NUMERICAL WEATHER FACILITY, MONTEREY, CALIFORNIA

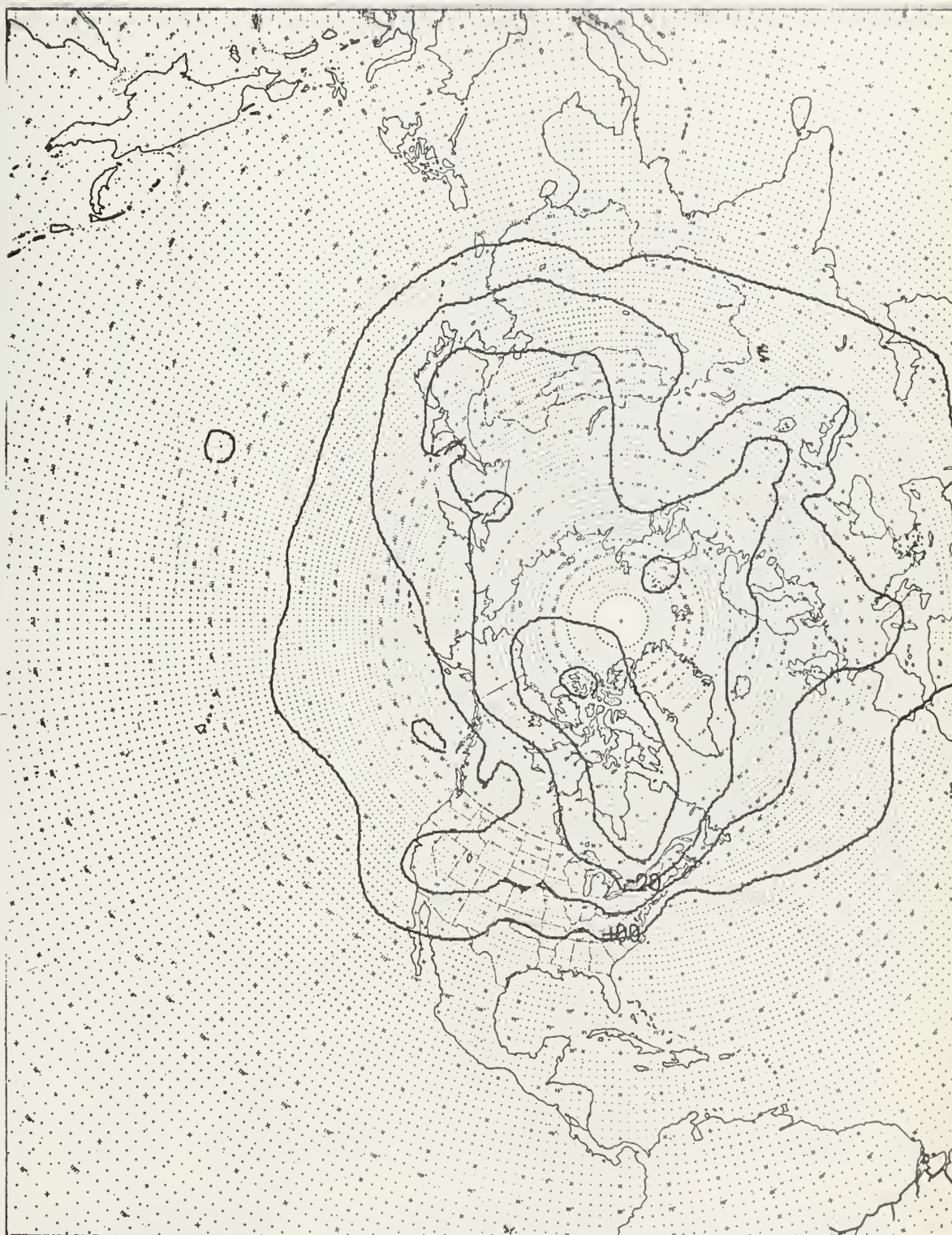
12Z 23 JAN 62 D 700



SCALE: 1:120,000,000

FLEET NUMERICAL WEATHER FACILITY, MONTEREY, CALIFORNIA

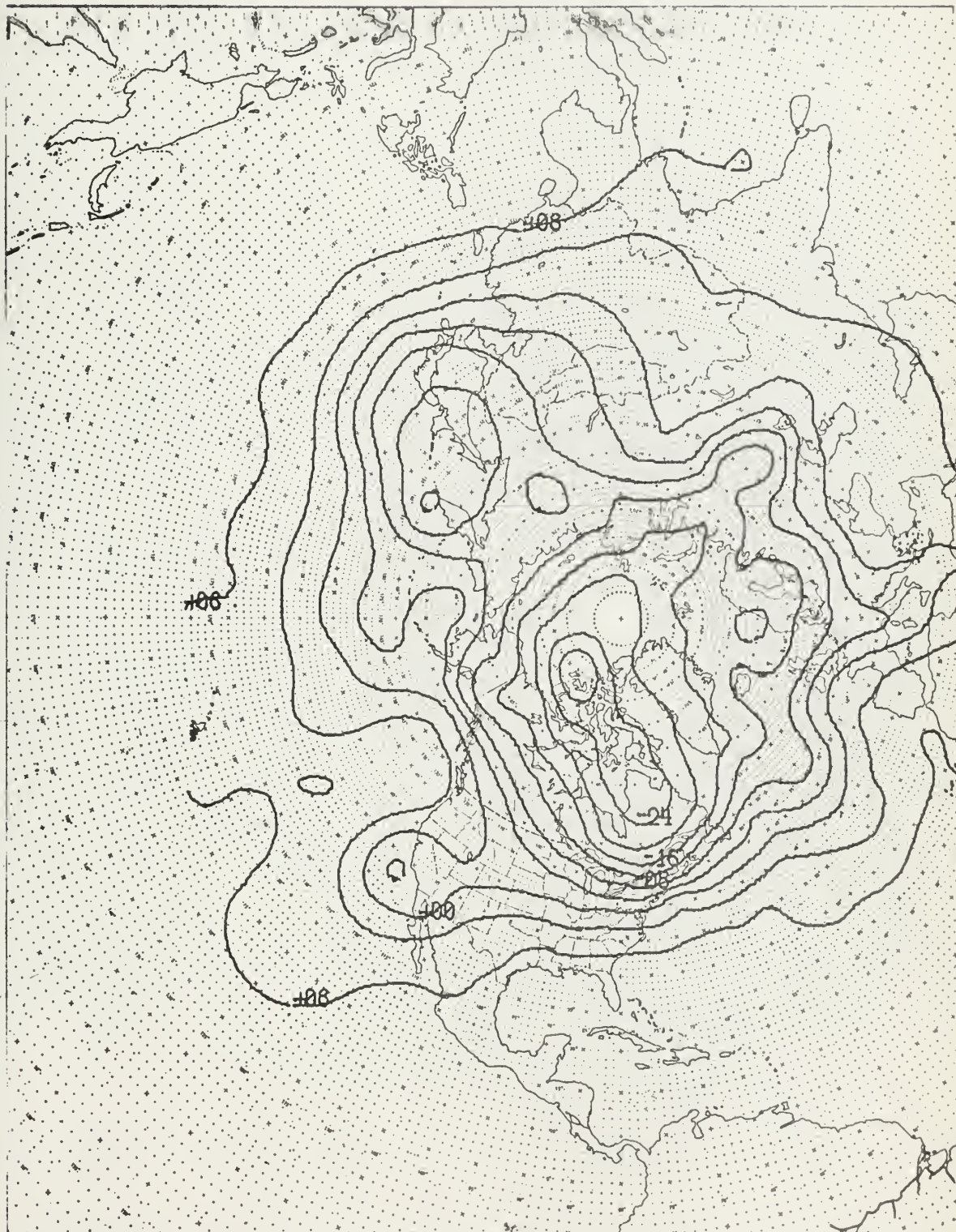
12Z 23 JAN 62 T 700



SCALE: 1:120,000,000

FLEET NUMERICAL WEATHER FACILITY, MONTEREY, CALIFORNIA

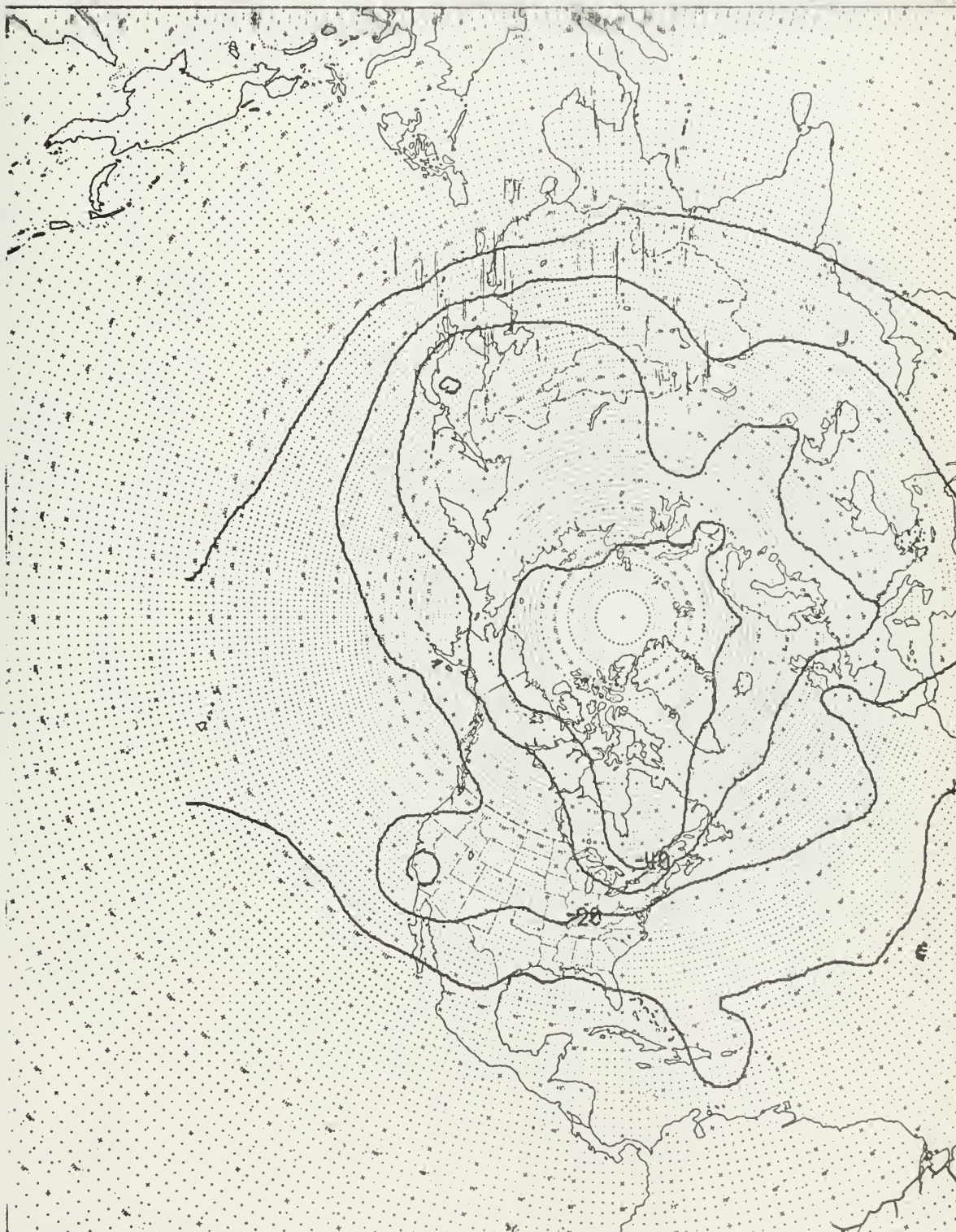
12Z 23 JAN 62 D 500



SCALE: 1:120,000,000

FLEET NUMERICAL WEATHER FACILITY, MONTEREY, CALIFORNIA

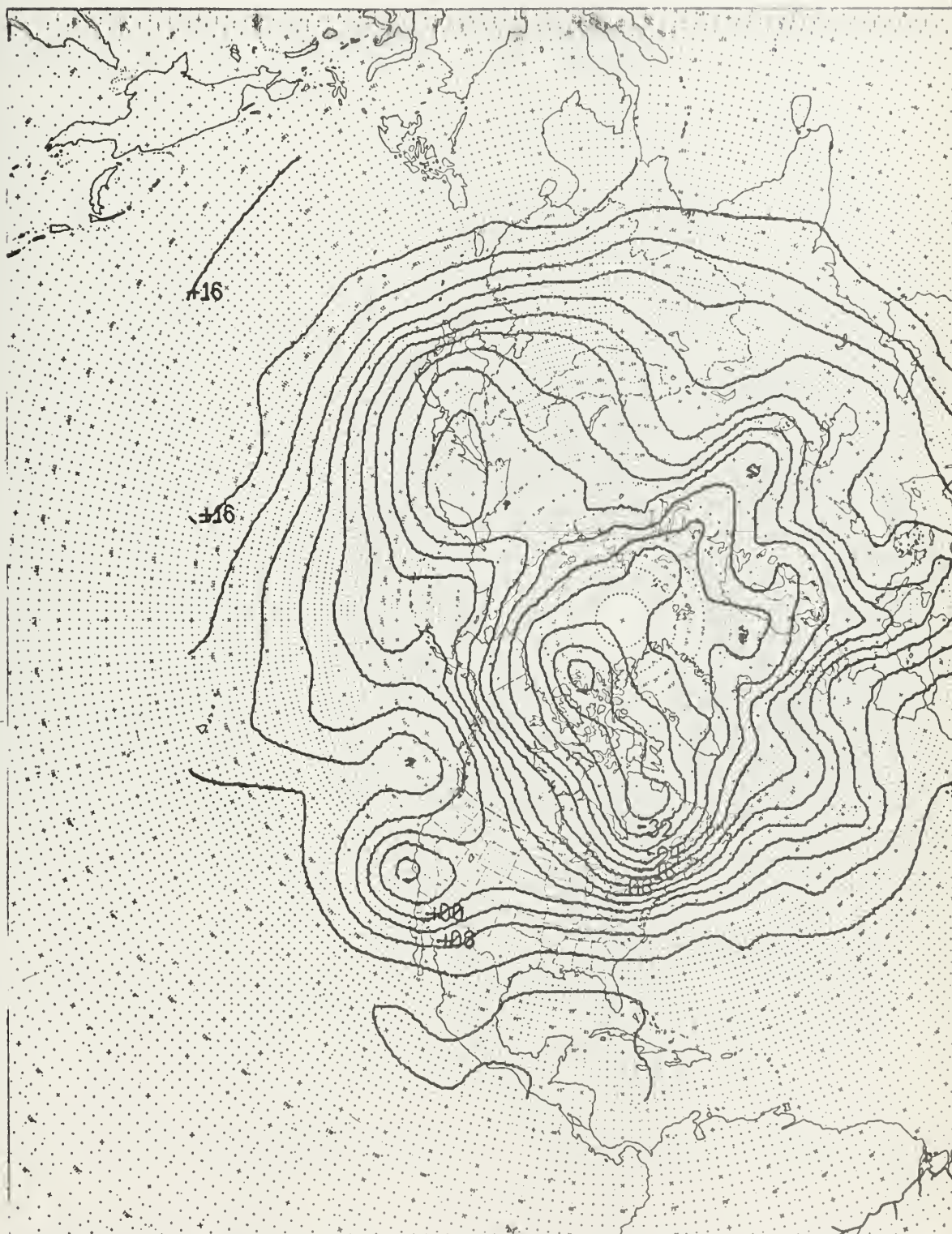
12Z 23 JAN 62 T 500



SCALE: 1:120,000,000

FLEET NUMERICAL WEATHER FACILITY, MONTEREY, CALIFORNIA

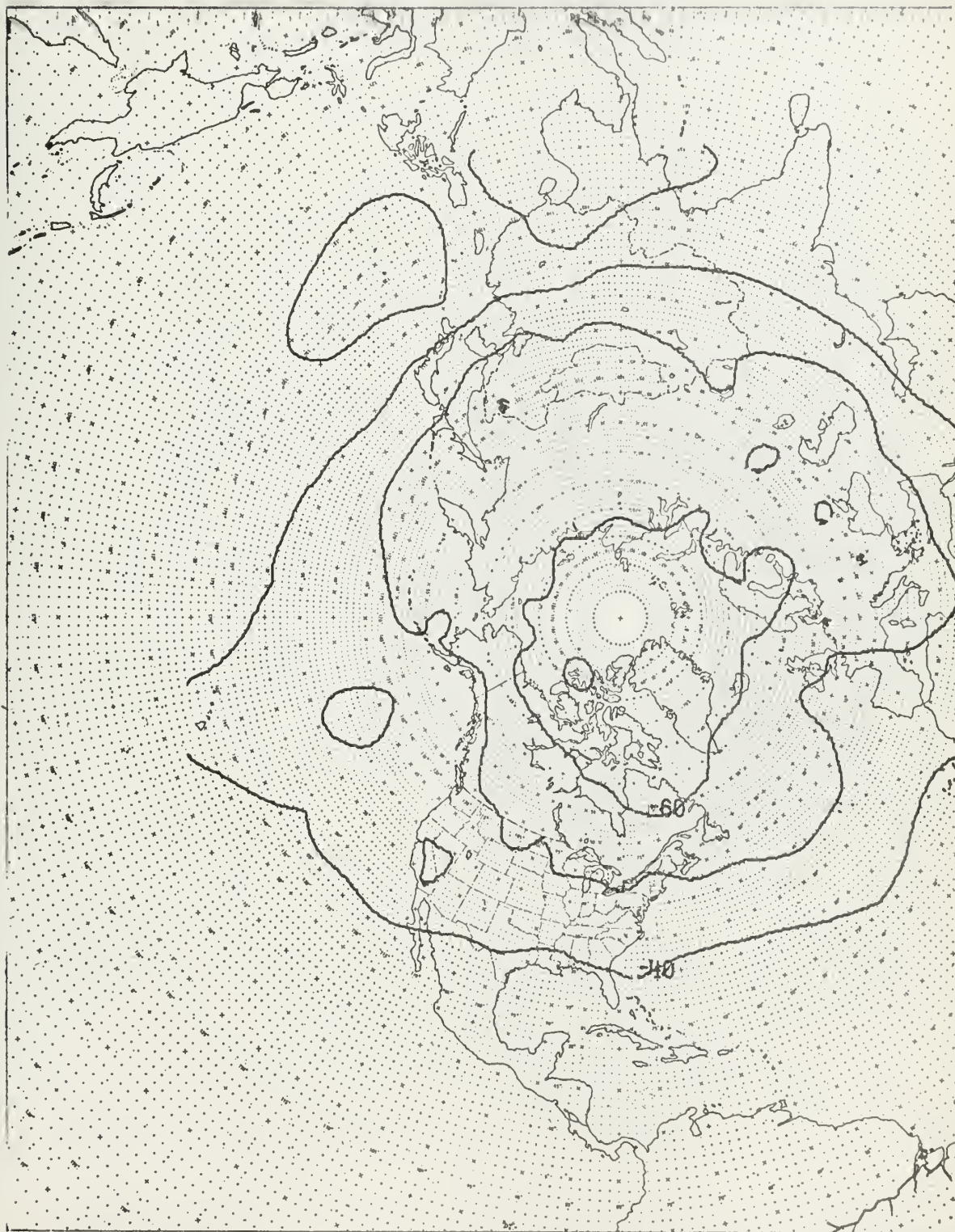
12Z 23 JAN 62 D 300



SCALE: 1:120,000,000

FLEET NUMERICAL WEATHER FACILITY, MONTEREY, CALIFORNIA

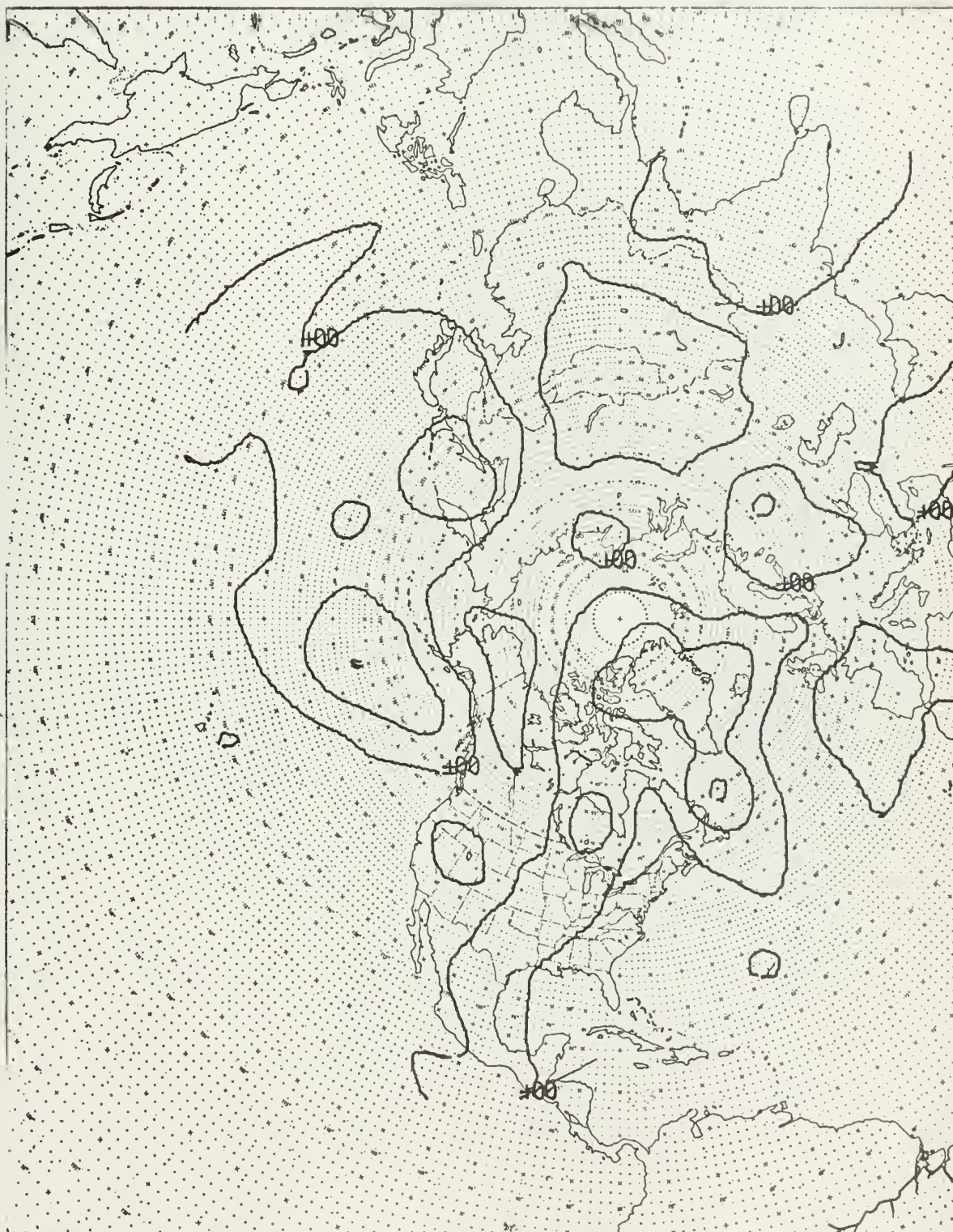
12Z 23 JAN 62 T 300



SCALE: 1:120,000,000

FLEET NUMERICAL WEATHER FACILITY, MONTEREY, CALIFORNIA

12Z 26 JAN 62 D 1000



SCALE: 1:120,000,000

FLEET NUMERICAL WEATHER FACILITY, MONTEREY, CALIFORNIA

12Z 26 JAN 62 D 500






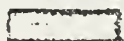






SCALE: 1:120,000,000

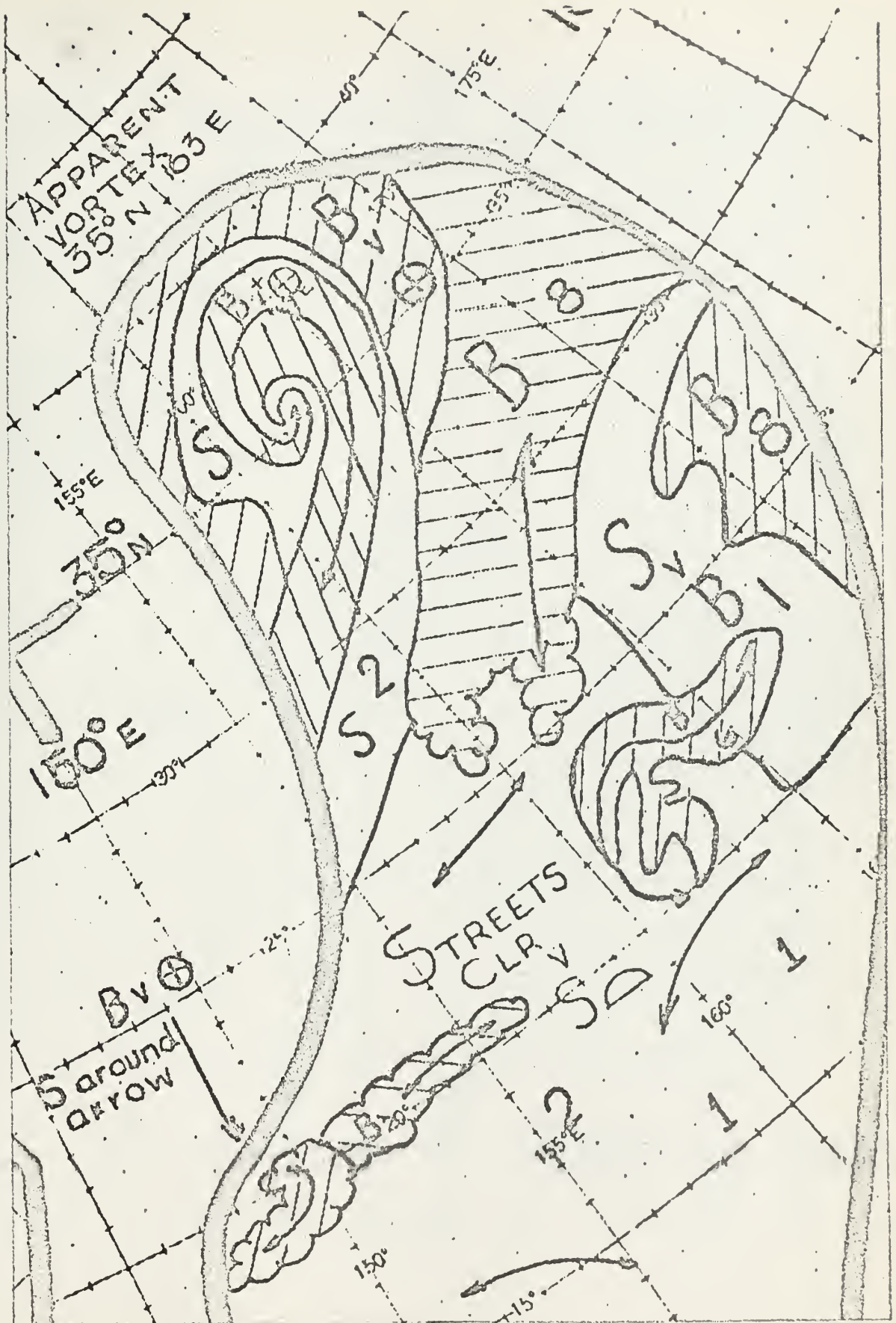
FLEET NUMERICAL WEATHER FACILITY, MONTEREY, CALIFORNIA

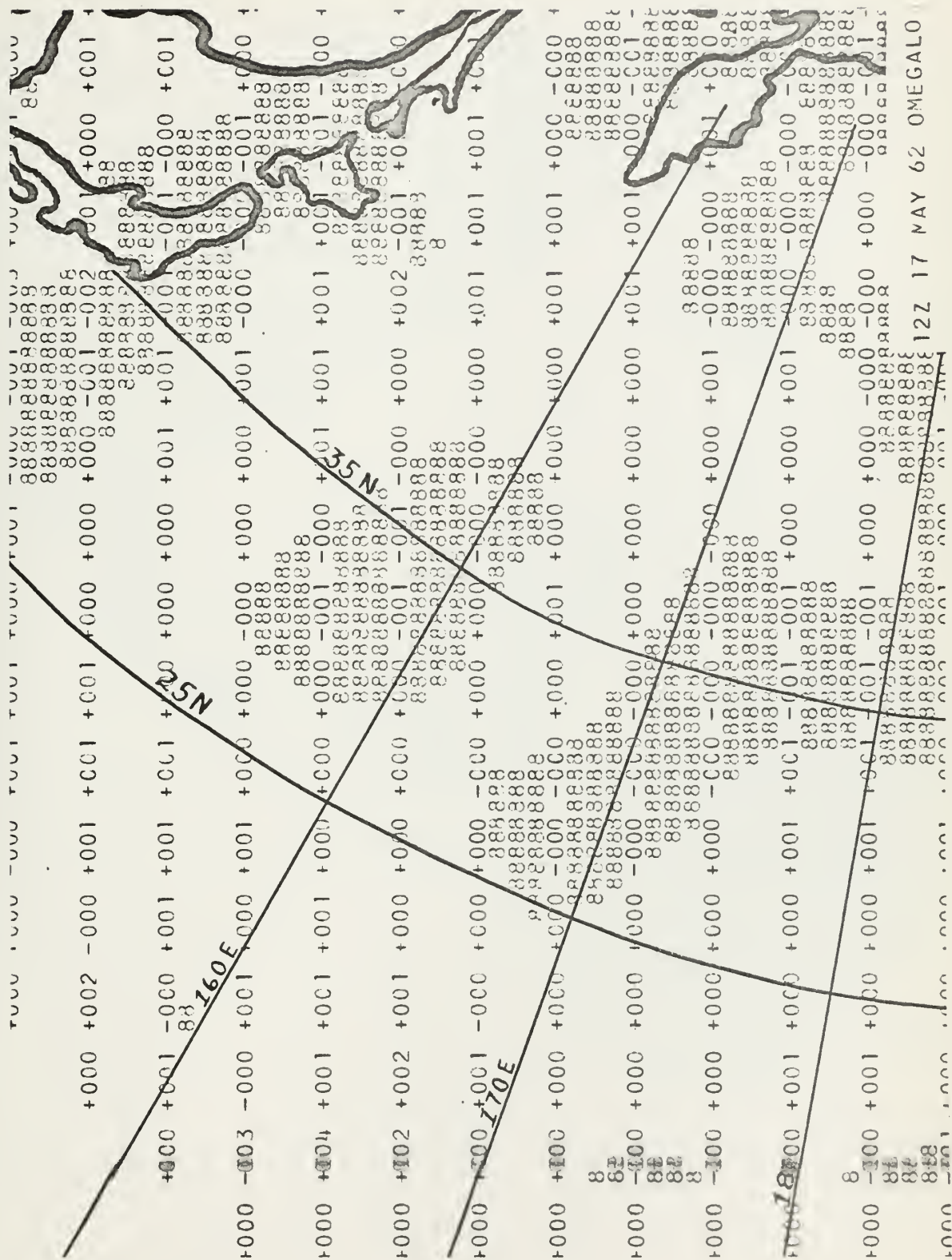
APPENDIX D

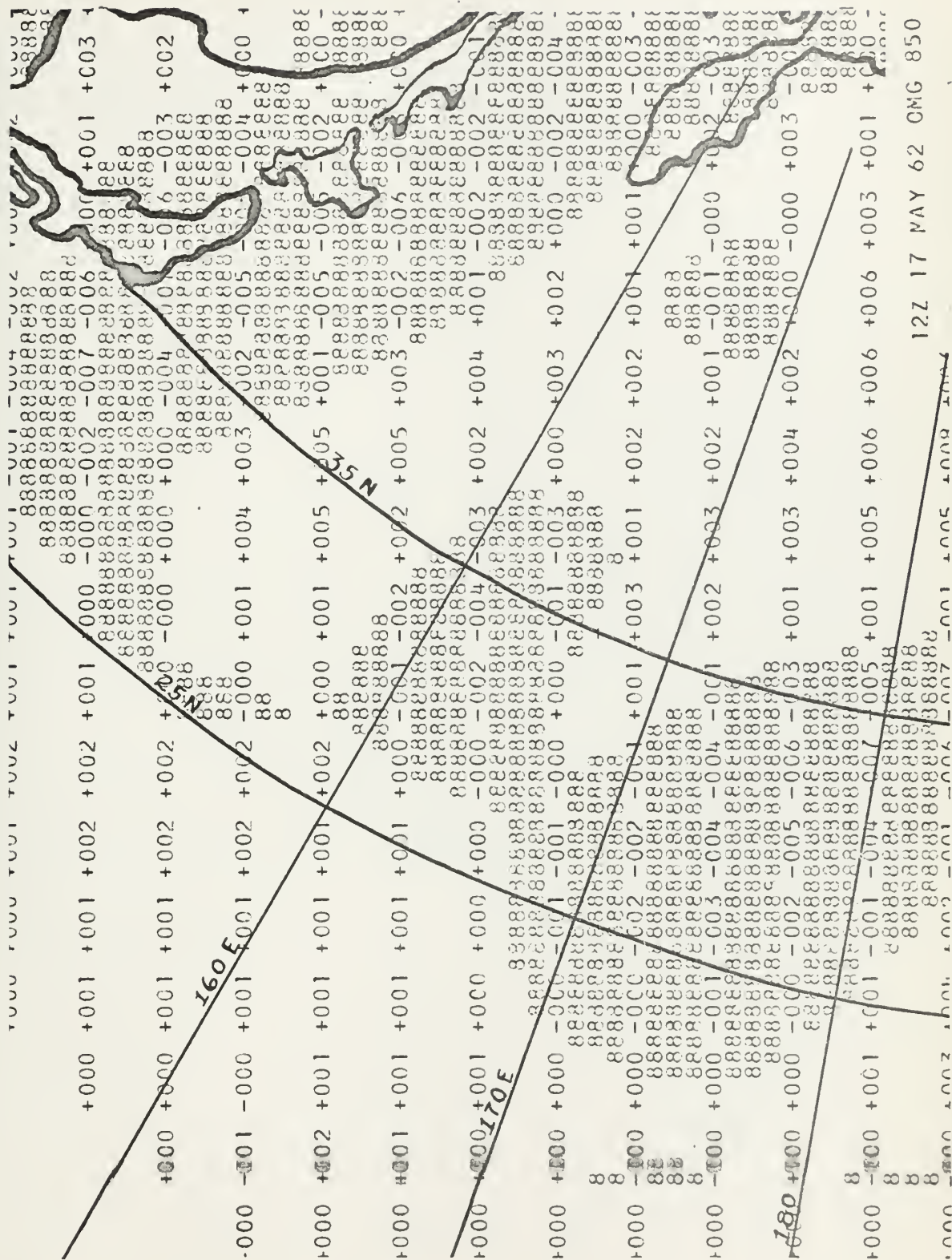
TIROS OBSERVATIONS AND CORRESPONDING OMEGA FIELDS

MAJOR	BOUNDARY	
MINOR	BOUNDARY	
CLEAR	CLR	
SCATTERED	S	STFM 
BROKEN	B 	CUFM 
OVERCAST	⊕ 	CIFM 
HEAVY	+	CB 
THIN	-	BANDS 
		VORTEX 
<u>CLOUD</u>	<u>SIZE (N.M.)</u>	<u>OPEN SPACES</u>
1	0-30	6
2	30-60	7
3	60-90	8
4	90-120	9

TIROS CODE





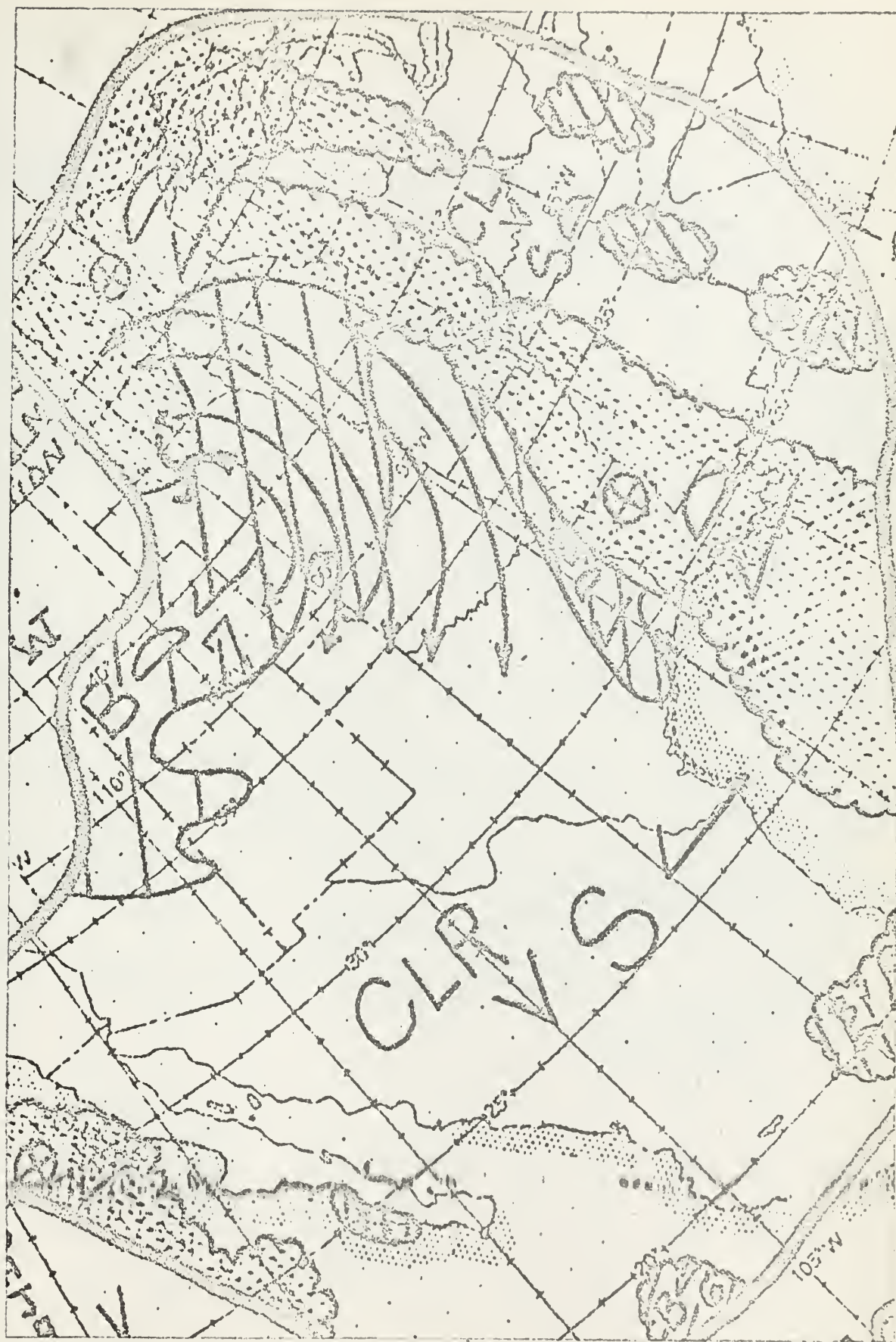


12Z 17 MAY 62 OMG 850

12Z 17 MAY 62 CMG 7001

12Z 17 MAY 62 CMG 5001

[illegible]



00Z 30 MAR 62 CMEGALO 14

002 30 MAY 62 OMG 850

002 30 MAY 62 CMG 700

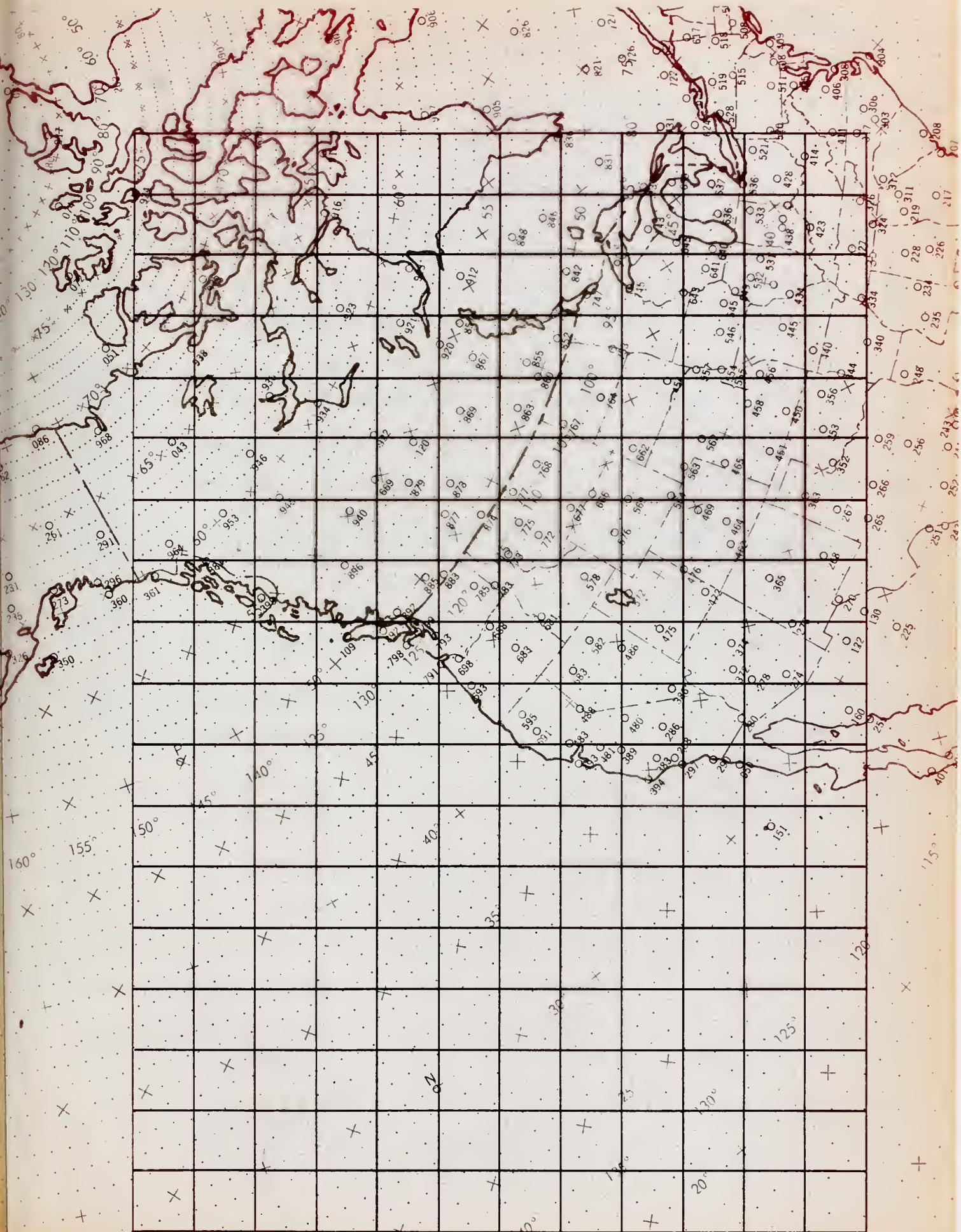
00Z 30 MAR 62 QMG 500

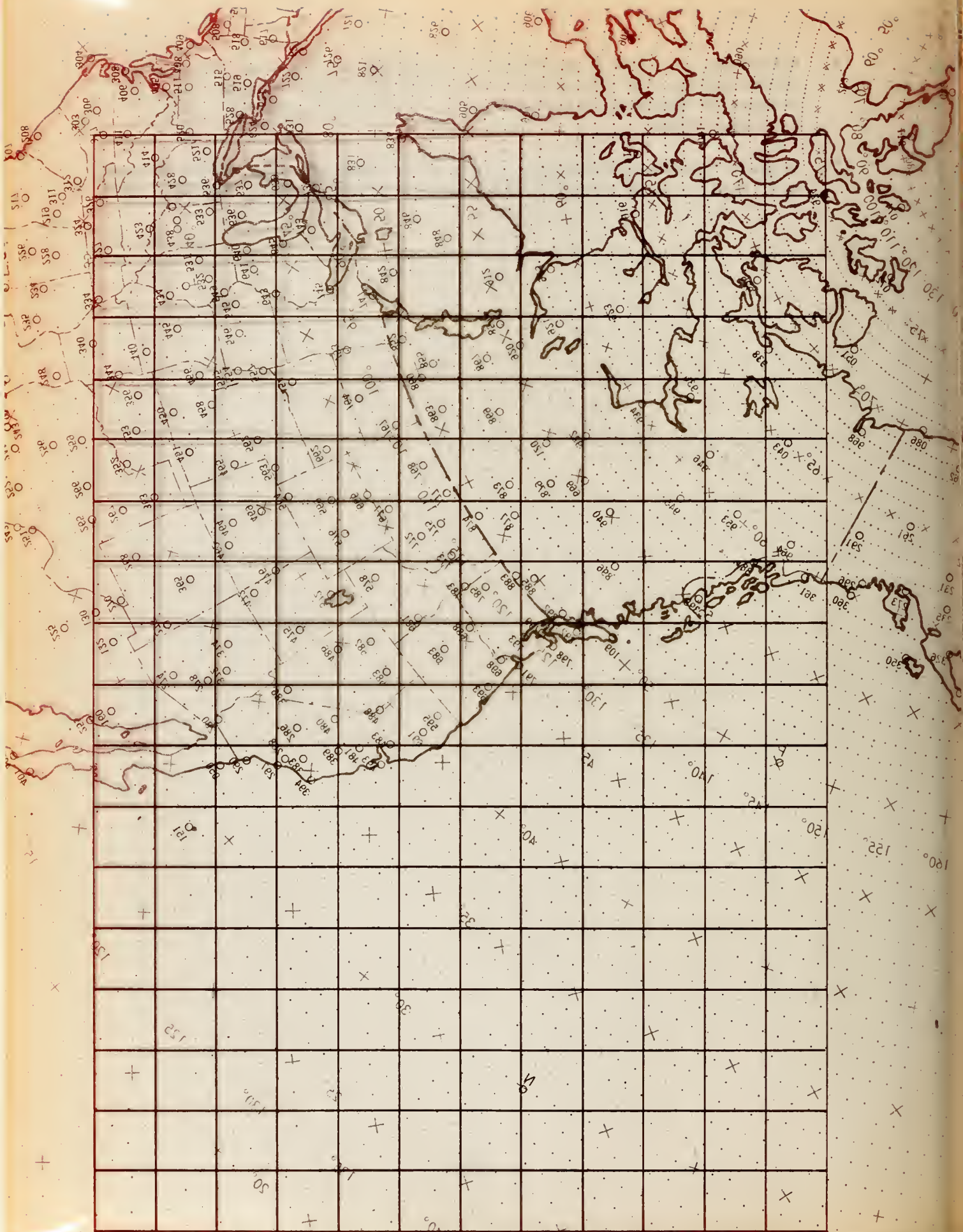
[illegible]

BIBLIOGRAPHY

1. Synoptic meteorology as practiced by the National Meteorological Center, Part II, U. S. Government Printing Office, Washington, D.C., November 1961.
2. Semi-annual progress report, Fleet Numerical Weather Facility, Monterey, Calif., April 1962.
3. Stuart, D.W., Vertical motion and the baroclinic mechanism of rapid upper level cyclogenesis, Dept. of Meteorology, University of California, Los Angeles, December 1961.
4. Wiin-Nielsen, A., On certain integral constraints for the time-integration of baroclinic models, *Tellus*, vol. 11, No. 1, 1959, p 45-59.
5. Gates, W.L., The stability properties and energy transformations of the two-layer model of variable static stability, *Tellus*, vol. 13, No. 4, 1961, p 460-471.
6. Wiin-Nielsen, A., On a graphical method for an approximate determination of the vertical velocity in the mid-troposphere, *Tellus*, vol. 11, No. 4, 1959, p 432-440.
7. Gates, W.L., Static stability measures in the atmosphere, Scientific Report No. 3, Dynamical Weather Prediction Project, Dept. of Meteorology, University of California, Los Angeles, October 1960.
8. Salvadori and Baron, Numerical methods in engineering, Prentice Hall, New York, 1952, p 47-49.
9. 'Arnason, G., Convergence rates of Liebmann's and Richardson's iterative methods when applied to the solution of a system of Helmholtz-type equations, Tech. Memo No. 10, Joint Numerical Weather Prediction Unit, U. S. Weather Bureau, July 1956.
10. Sawyer, J.S., The introduction of the effects of topography into methods of numerical forecasting, *Quarterly Journal of the Royal Meteorological Society*, vol. 85, No. 363, 1959, p 31-43.
11. Bellamy, J.C., The use of pressure altitude and altimeter corrections in meteorology, *Journal of Meteorology*, vol. 2, No. 1, 1945.
12. Lettau, H.H., Studies of the three-dimensional structure of the planetary boundary layer, Annual Report, Dept. of Meteorology, University of Wisconsin, August 1961, p 143-170.
13. Cressman, G.P., Improved terrain effects in barotropic forecasts, *Monthly Weather Review*, vol. 88, Nos. 9-12, 1960, p 317-342.

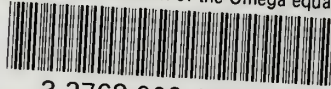
14. Berkofsky, L., and E. A. Bertoni, Topographic charts at one-degree intersections for the entire earth, GRD Research Notes No. 42, Geophysics Research Directorate, U. S. Air Force, Bedford, Mass., September 1960.
15. Ikegami-Hirofumi, A synoptic study of the January 1962 Monterey snow, M.S. thesis, U. S. Naval Postgraduate School, Monterey, Calif., 1962.





thesC496

Hemispheric solution of the Omega equati



3 2768 002 10283 2
DUDLEY KNOX LIBRARY